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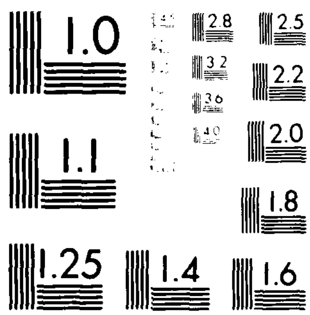

MICROCOPY RESOLUTION TEST CHART

DCS/ACC PACIFIC EW SURVIVABILITY STUDY

SECTION III ENGINEERING CALCULATIONS

27 JULY 1981

conducted by

UNITED STATES ARMY COMMUNICATIONS [illegible]
Deputy Chief of Staff for [illegible]
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FOREWORD

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PART 1 - LINK AVAILABILITY

1.1 Introduction. LOS, tropo, diffraction, and satellite links all experience signal variations as a function of time and RF signal path length, commonly referred to as fading. Fading occurs when microwave signals arrive simultaneously at a receiving antenna over more than one path and result from the fact that at certain times these signals will be out of phase, cancelling each other. Fading is caused by a combination of climatic and terrain factors; therefore, it is difficult to predict the frequency and depth of fades that can occur over a given path. The discussions which follow delineate the methods used to predict the probability of a fade and the fade outage statistics which have a bearing on the performance of a particular link. The methods are derived for LOS, tropo, diffraction, and satellite links. In addition, failure thresholds for these types of links are discussed, which permit the calculation of required processing gain (antijam) for ECCM applications. Sample calculations are also provided for typical LOS, tropo, and satellite links. The methodology described in the subsequent paragraphs is derived from references 1 through 5, part 5, this section.

1.2 LOS Links

1.2.1 Fade Outage Statistics

a. The probability distribution of the signal envelope voltage (V) for LOS paths is given by the equation:

$$P(V<L) = rL^2 \tag{1}$$

where

P = probability, or fraction of time, T, that V is < L

L = the normalized algebraic value of envelope voltage (see fig. 1-1)

r = the multipath occurrence factor for heavy fading months

b. The factor r is given by:

$$r = ab\left(\frac{f}{4}\right)D^3\ 10^{-5} \tag{2}$$

or

$$r = a \times b \times 2.5 \times 10^{-6} \times f \times D^3 \tag{3}$$

where

a = terrain factor (numeric) which takes into account the terrain roughness for three climatic conditions. The terrain factor may be either a representative value (see fig. 1-2) or a calculated value (see fig. 1-3) from path profiles

b = climate factor (numeric), which accounts for the effect of climate on fading (see fig. 1-4)

(Text continued on page 1-6)

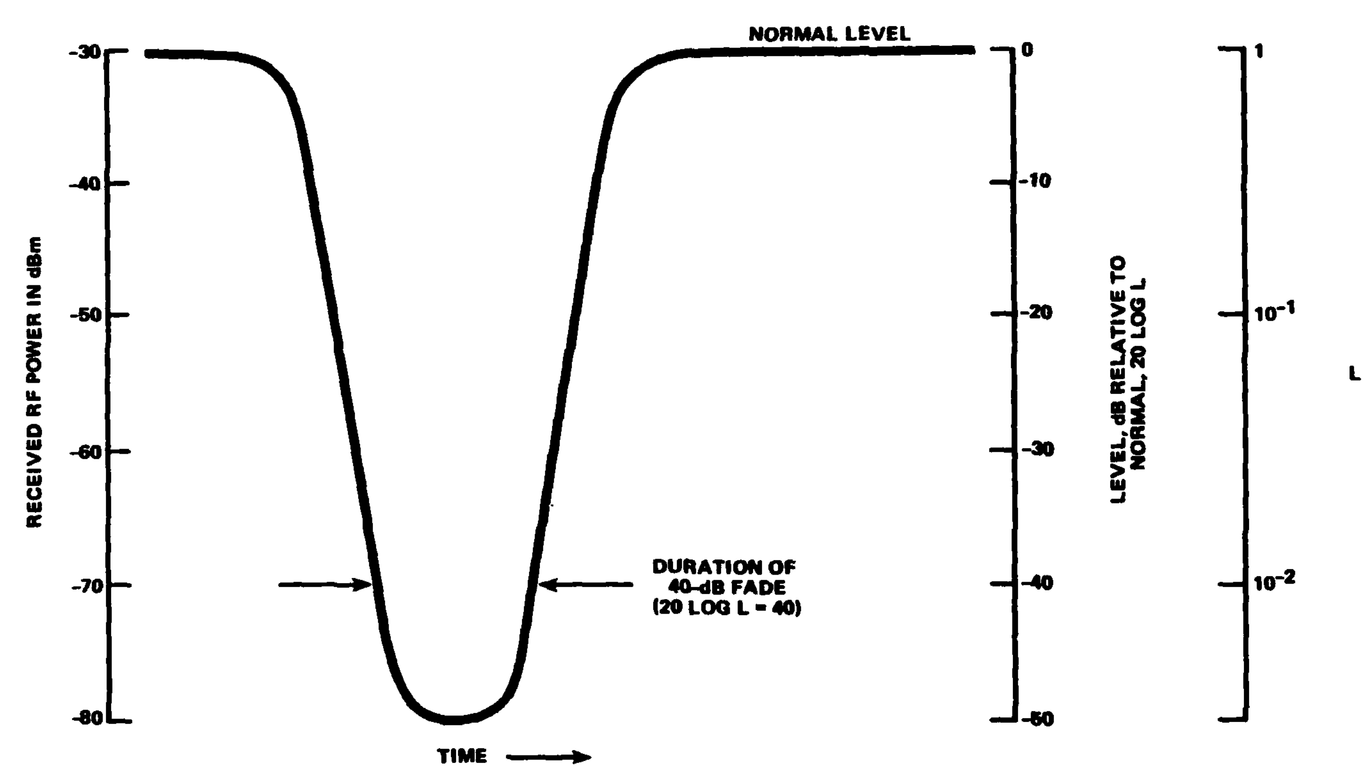


Figure 1-1. Definitions of L and fade duration.

Terrain Type	Terrain Roughness (ft)	Coastal Climate	Terrain Factor, a Average Climate	Dry Climate
Smooth	20	6.6	3.3	1.6
Normal	50	2.0	1.0	0.3
Rough	140	1.6	0.5	0.1

Figure 1-2. Representative values of terrain factor.

Climate	Terrain Factor Equation
Coastal	$a = 2(W/50)^{-1.3}$
Average	$a = (W/50)^{-1.3}$
Dry	$a = 0.5\ (W/50)^{-1.3}$

where

a = terrain factor (numeric)
W = the terrain roughness (ft)

$$W = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (X_i - M)^2}$$

$$M = \frac{1}{N} \sum_{i=1}^{N} X_i$$

where

N = the number of terrain points

M = the mean roughness (ft)

Figure 1-3. Terrain factor calculations.

Climate	Climate Factor, b
Gulf coast, or similar hot, humid areas	0.5
Normal interior temperate, or northern	0.25
Mountainous, or very dry	0.125

Figure 1-4. Climate factor.

f = frequency (GHz)

D = path length (statute miles)

c. The relationship of the link fade margin (F) to L is given (from fig. 1-1) by:

$$F = -20 \log L \tag{4}$$

hence,

$$L^2 = 10^{-F/10} \tag{5}$$

Since P(V<L) is really the probability of a fade outage (P_o) -- that is, the probability that V will be less than the threshold level, L -- then equation 1 can be rewritten, in terms of fade margin, as:

$$P_o = a \times b \times 2.5 \times 10^{-6} \times f \times D^3 \times 10^{-F/10} \tag{6}$$

d. However, equation 6 does not consider the effects of diversity operation. Diversity can be accounted for by an improvement factor (I).

(1) For frequency diversity, the improvement factor (I_{fd}) is given by:

$$I_{fd} = c\left(\frac{\Delta f}{f}\right) \times 10^{F/10} \tag{7}$$

where

c = the frequency factor (see fig. 1-5)

Δf = the frequency diversity spacing (GHz)

Equations 6 and 7 can be combined so that P_o may be calculated for the frequency diversity condition by:

$$P_o(fd) = \frac{a \times b \times 2.5 \times 10^{-6} \times f^2 \times 10^{-2F/10}}{c \times \Delta f} \tag{8}$$

(2) For space diversity, the improvement factor (I_{sd}) is given by:

$$I_{sd} = \frac{7 \times 10^{-5} \times f \times S^2 \times 10^{\overline{F}/10}}{D} \tag{9}$$

where

S = the vertical antenna spacing between centers (ft)

$\overline{F}$ = the fade margin (dB) associated with the second antenna, or the smaller of the two fade margins

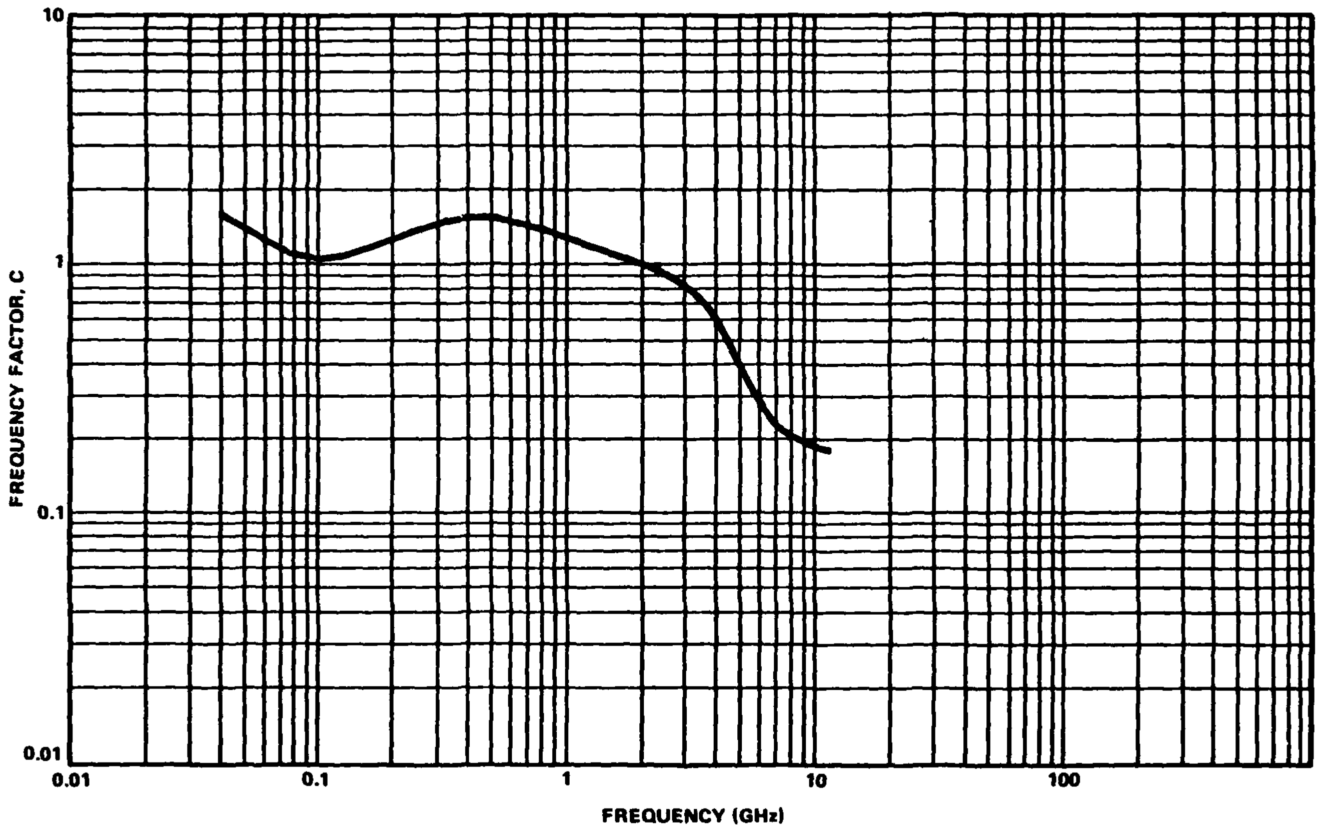


Figure 1-5. Frequency factor.

Equations 6 and 9 can be combined so that P_o may be calculated for the space diversity conditions by:

$$P_o(sd) = \frac{a \times b \times 3.57 \times 10^{-2} \times D^4 \times 10^{-F/10}}{S^2 \times 10^{\overline{F}/10}} \qquad (10)$$

For practical reasons in this study, the difference between the two fade margins was considered to be negligible and, hence, $\overline{F}$ was considered to be equal to $F(\overline{F}=F)$.

Therefore, equation 10 can be rewritten as:

$$P_o(sd) = \frac{a \times b \times 3.57 \times 10^{-2} \times D^4 \times 10^{-2F/10}}{S^2} \qquad (11)$$

(3) For quadruple (quad) diversity, the improvement factor (I_{qd}) is given by:

$$I_{qd} = I_{fd} \times I_{sd}$$

$$= c\left(\frac{\Delta f}{f} \times 10^{F/10}\right)\left(\frac{7 \times 10^{-5} \times f \times S^2 \times 10^{\overline{F}/10}}{D}\right) \qquad (12)$$

Hence, P_o for the quad diversity condition is given by:

$$P_o(qd) = \frac{a \times b \times 3.57 \times 10^{-2} \times f \times D^4 \times 10^{-3F/10}}{c \times \Delta f \times S^2} \qquad (13)$$

where $F = \overline{F}$, as with the space diversity condition.

1.2.2 Availability Equations

a. Availability - General. Link availability is the fraction of time (T) that the signal envelope voltage (V) will be above threshold, L. Hence, link availability (A) is defined as:

$$A = 1 - P_o \qquad (14)$$

(1) Link availability for the nondiversity condition is given by:

$$A(nd) = 1 - \left(a \times b \times 2.5 \times 10^{-6} \times f \times D^3 \times 10^{-F/10}\right) \qquad (15)$$

(2) Link availability for the frequency diversity condition is given by:

$$A(fd) = 1 - \left(\frac{a \times b \times 2.5 \times 10^{-6} \times f^2 \times D^3 \times 10^{-2F/10}}{c \times \Delta f}\right) \qquad (16)$$

(3) Link availability for the space diversity condition is given by:

$$A(sd) = 1 - \left(\frac{a \times b \times 3.57 \times 10^{-2} \times D^4 \times 10^{-2F/10}}{S^2} \right) \qquad (17)$$

(4) Link availability for the quad diversity condition is given by:

$$A(qd) = 1 - \left(\frac{a \times b \times 3.57 \times 10^{-2} \times f \times D^4 \times 10^{-3F/10}}{c \times \Delta f \times S^2} \right) \qquad (18)$$

(5) For convenient reference, the availability equations are presented in summary form in figure 1-6.

b. Baseline Link Availability

(1) The baseline link availability (A_S) is the link availability when no jamming is present. It is calculated using the appropriate availability equation (fig. 1-6) and appropriate link parameters. The link fade margin, with no jamming present, is the difference between the received signal level, S_{REC} (dBm), and the required signal level, S_{REQ} (dBm), that is --

$$F_S = S_{REC} - S_{REQ} \text{ (dB)} \qquad (19)$$

(2) S_{REC} (dBm) is calculated using the equation:

$$S_{REC} = P_T + G_T + G_R - L_T - L_R - L_S \text{ (dBm)} \qquad (20)$$

where

P_T = transmitter output power (dBm)

G_T = transmitter antenna gain (dB)

G_R = receiver antenna gain (dB)

L_T = transmitter antenna system losses (dB)

L_R = receiver antenna system losses (dB)

L_S = propagation path loss (dB)

(3) Propagation path loss (L_S) is calculated for LOS links by the equation:

$$L_S = 97.0 + 20 \log f + 20 \log D + A_a \qquad (21)$$

where

1. Nondiversity:

$$A = 1 - (a \times b \times 2.5 \times 10^{-6} \times f \times D^3 \times 10^{-F/10})$$

2. Frequency Diversity:

$$A = 1 - \left(\frac{a \times b \times 2.5 \times 10^{-6} \times f^2 \times D^3 \times 10^{-2F/10}}{c \times \Delta f}\right)$$

3. Space Diversity:

$$A = 1 - \left(\frac{a \times b \times 3.57 \times 10^{-2} \times D^4 \times 10^{-2F/10}}{S^2}\right)$$

4. Quad Diversity:

$$A = 1 - \left(\frac{a \times b \times 3.57 \times 10^{-2} \times f \times D^4 \times 10^{-3F/10}}{c \times \Delta f \times S^2}\right)$$

where

A = availability
a = terrain factor (numeric)
b = climate factor (numeric)
c = frequency factor (numeric)
f = frequency (GHz)
D = path length (statute miles)
F = fade margin (dB) (Note: In the case of space diversity, the fade margin associated with the first antenna, or the larger of the two fade margins)
Δf= the frequency diversity spacing (GHz)
S = vertical antenna spacing between centers (ft)

Figure 1-6. Availability equations - LOS.

f = frequency (GHz)

D = path length (statute miles)

A_a = absorption by water vapor and oxygen (dB) — discussed in more detail in paragraph 1.5.1

(4) S_{REQ} (dBm) is calculated by the equation:

$$S_{REQ} = -138.6 + 10 \log T + 10 \log B + NF + S/N_{REQ} \quad (22)$$

where

T = system operating temperature in degrees Kelvin (for LOS links $T = 290°K$)

B = receiver IF 3-dB bandwidth (MHz)

NF = receiver system noise figure (dB)

S/N_{REQ} = signal-to-noise ratio required to produce acceptable system output (dB) (for LOS systems, S/N_{REQ} = 10 dB)

c. Link Availability in the Presence of Jamming

(1) The link availability when jamming is present (A_J) is calculated using the appropriate equation of figure 1-6. The link fade margin in the presence of jamming (F_J) is the difference between S_{REC} (dBm) and the received jamming signal level, J_{REC} (dBm), that is:

$$F_J = S_{REC} - J_{REC} \text{ (dB)} \quad (23)$$

(2) J_{REC} (dBm) is calculated by the equation:

$$J_{REC} = ERP_J + G_{RJ} - L_R - L_J + 10 \log B - 10 \log B_J \quad (24)$$

where

ERP_J = jammer effective radiated power (dBm)

G_{RJ} = receiver antenna gain in the direction of the jammer (dB)

B_J = jammer 3-dB emission bandwidth (MHz)

L_J = propagation path loss between jammer and link receiver (dB)

(3) Propagation path loss for the jammer (L_K) is calculated by the equation:

$$L_J = 97.0 + 20 \log f + 20 \log D_J + A_a \tag{25}$$

where

D_J = path length between jammer and link receiver (statute miles)

1.2.3 <u>Failure Threshold</u>. The failure threshold is the value of fade margin below which the link is considered to be below the DCA availability criterion.

1.2.3.1 <u>DCA LOS Link Availability Criterion</u>. The availability criterion value for DCS LOS links is 0.99996, as given in TR-12-76. This criterion value is denoted A_C for the purposes of this study.

1.2.3.2 <u>Required Jamming Margin</u>. The fade margin required in the presence of jamming (F_C), is the signal-to-jamming ratio (S/J) in dB required to restore the link to the DCA availability criterion (A_C). The calculation of F_C for LOS is dependent upon the types of diversity operation employed by the specific system.

a. *For nondiversity operation:*

$$F_C(nd) = -10 \log \left(\frac{1 - A_C}{a \times b \times 2.5 \times 10^{-6} \times f \times D_S^3} \right) \tag{26}$$

b. For frequency diversity operation:

$$F_C(fd) = \left\{ -10 \log \left[\frac{\left(1 - A_C\right)\left(c \times \Delta f\right)}{a \times b \times 2.5 \times 10^{-6} \times f^2 \times D_S^3} \right] \right\} \Big/ 2 \tag{27}$$

c. For space diversity operation:

$$F_C(sd) = \left\{ -10 \log \left[\frac{\left(1 - A_C\right) s^2}{a \times b \times 3.57 \times 10^{-2} \times D_S^4} \right] \right\} \Big/ 2 \tag{28}$$

d. For quad diversity operation:

$$F_C(qd) = \left\{ -10 \log \left[\frac{\left(1 - A_C\right)\left(c \times \Delta f \times s^2\right)}{a \times b \times 3.57 \times 10^{-2} \times f \times D_S^4} \right] \right\} \Big/ 3 \tag{29}$$

1.2.3.3 Required Processing Gain. The required processing gain (G_p, in dB) is the amount of ECCM required to restore the link to the DCA availability criterion (A_C). Required G_p is given by:

$$\text{Required } G_p = F_C - F_J \text{ (dB)} \tag{30}$$

1.2.4 Sample Calculations. Presented herein are sample calculations for a typical LOS link. The link selected for this example is the link between Richmond and Highpoint (M1235) in the Korean backbone. The link employs AN/FRC-109(V) radios with frequency diversity operation. However, in the interest of brevity, calculations will be performed for only one of the frequency pair.

1.2.4.1 Baseline Link Availability

a. The baseline link availability for link M1235 is calculated using the availability equation for frequency diversity operation (equation 16), repeated here:

$$A(fd) = 1 - \left(\frac{a \times b \times 2.5 \times 10^{-6} \times f^2 \times D^3 \times 10^{-2F/10}}{c \times \Delta f} \right)$$

The parameters for link M1235 (Richmond to Highpoint) are:

$a = 0.3$

$b = 0.25$

$f = 7.170$ GHz

$D = D_s = 37.5$ statute miles

$c = 0.21$

$\Delta f = 0.330$ GHz

b. The fade margin (F_S) is calculated using equations 19 and 20, repeated here:

$$F_S = S_{REC} - S_{REQ} \text{ (dB)}$$

$$S_{REC} = P_T + G_T + G_R - L_T - L_R - L_S \text{ (dBm)}$$

The parameters for link M1235 are:

$P_T = 27$ dBm

$G_T = 44.6$ dB

$G_R = 44.6$ dB

$L_T = 2.3$ dB

$L_R = 1.7$ dB

$L_S = 146.5$ db

$S_{REC} = 27 + 44.6 + 44.6 - 2.3 - 1.7 - 146.5$

$= -34.9$ dBm

The S_{REQ} for the AN/FRC-109(V) for M1235 is -77 dBm and, thus, the fade margin (F_S) is:

$F_S = -34.9 - (-77) = 42.1$ dB

c. The baseline availability can now be calculated as follows:

$$A_S(fd) = 1 - \left(\frac{0.3 \times 0.25 \times 2.5 \times 10^{-6} \times (7.170)^2 \times (37.5)^3 \times 10^{-84.2/10}}{0.21 \times 0.330} \right)$$

$$A_S(fd) = 1 - \left(\frac{0.3 \times 0.25 \times 2.5 \times 10^{-6} \times 51.4 \times 52{,}734 \times 3.8046 \times 10^{-9}}{0.0693} \right)$$

$$A_S(fd) = 1 - 2.7901 \times 10^{-8}$$

$$A_S(fd) = 0.9999999$$

1.2.4.2 Link Availability in Presence of Jamming

a. Consider link M1235 operating in the presence of a hypothetical airborne noise jammer at a distance of 10 miles from the receiver at Highpoint. The same availability equation (equation 16) is used:

$$A(fd) = 1 - \left(\frac{a \times b \times 2.5 \times 10^{-6} \times f^2 \times D^3 \times 10^{-2F/10}}{c \times \Delta f} \right)$$

However, the availability will be denoted A_J and the fade margin, F_J.

b. The fade margin is calculated by equation 23:

$$F_J = S_{REC} - J_{REC} \text{ (dB)}$$

J_{REC} is calculated by equation 24:

$$J_{REC} = ERP_J + G_{RJ} - L_R - L_J - 10 \log B - 10 \log B_J$$

The parameters used are:

ERP_J = 70 dBm

G_{RJ} = 24.6 dB

L_R = 1.7 dB

L_J = 134.4 dB (from equation 25) for a distance of 10 miles

B = 20 MHz

B_J = 20 MHz

Thus, J_{REC} is calculated as:

$$J_{REC} = 70 + 24.6 - 1.7 - 134.4 + 13.0 - 13.0$$

$$= -41.5 \text{ dBm}$$

and

$$F_J = -34.9 - (-41.5) = 6.6 \text{ dB}$$

c. The A_J is then calculated as:

$$A_J(fd) = 1 - \left(\frac{0.3 \times 0.25 \times 2.5 \times 10^{-6} \times (7.170)^2 \times (37.5)^3 \times 10^{-13.2/10}}{0.21 \times 0.33} \right)$$

$$A_J(fd) = 1 - \left(\frac{0.3 \times 0.25 \times 2.5 \times 10^{-6} \times 51.4 \times 52{,}734 \times 4.7868 \times 10^{-2}}{0.0696} \right)$$

$$A_J(fd) = 1 - 0.3495353$$

$$A_J(fd) = 0.6504646$$

1.2.4.3 Failure Threshold. Comparison of the calculated A_J to the DCA availability criterion (A_C) reveals that the link is vulnerable to this jammer, that is, $A_J = 0.6504646$ and $A_C = 0.99996$, hence $A_J < A_C$.

1.2.4.4 Required Jamming Margin. The required jamming margin (F_C) is then calculated by equation 27:

$$F_C(fd) = \left\{ -10 \log \left[\frac{\left(1 - A_C\right)\left(c \times \Delta f\right)}{a \times b \times 2.5 \times 10^{-6} \times f^2 \times D_S^{\,3}} \right] \right\} \Big/ 2$$

Thus, for link M1235, F_C is calculated as:

$$F_C(fd) = \left\{ - 10 \log \left[\frac{(1-0.99996)\ \ (0.21 \times 0.33)}{0.3 \times 0.25 \times 2.5 \times 10^{-6} \times (7.17)^2 \times (37.5)^3} \right] \right\} \Big/ 2$$

$$F_C(fd) = \left[- 10 \log \left(\frac{2.772 \times 10^{-6}}{5.0822 \times 10^{-1}} \right) \right] \Big/ 2$$

$$F_C(fd) = \left[- 10 \log \left(5.4542 \times 10^{-6} \right) \right] \Big/ 2$$

$$F_C(fd) = 26.3 \text{ dB}$$

Hence, a fade margin of 26.3 dB is required to maintain the criterion availability of 0.99996.

1.2.4.5 Required Processing Gain. The processing gain required to restore link M1235 to the DCA availability criterion (A_C = 0.99996) is then calculated by equation 30:

$$\text{Required } G_p = F_C - F_J$$

$$\text{Required } G_p = 26.3 - 6.6$$

$$\text{Required } G_p = 19.7 \text{ dB}$$

Therefore, 19.7 dB of processing gain must be achieved by employing the available ECCM techniques, either singly or in combination, to restore the link to the DCA availability criterion.

1.3 Troposcatter and Diffraction Links

1.3.1 Fade Outage Statistics

a. The probability distribution of the signal envelope voltage (V) for troposcatter and diffraction links is given by the Rayleigh formula from Barnett (ref 1, part 5):

$$P(V<L) = 1 - e^{-L^2} \tag{31}$$

Since $P(V<L)$ is really the probability of a fade outage (P_o), and the relationship of L to the fade margin (F) is $F = -20 \log L$, equation 31 can be expressed as :

$$P_o = 1 - \exp\left(-10^{-F/10}\right) \tag{32}$$

b. Equation 31 does not consider the diversity combining techniques employed by tropo and diffraction systems. Combining is performed at one of two states in the receiver system: (1) before detection (predection), combining the individual signals before detection; and (2) after detection (post-detection), combining the individual signal inputs after detection at the baseband level. There are various means in which combining may be accomplished, whether pre- or post-detection is used. There are three common types of combiners:

(1) Selection Combiner: The selection combiner determines the larger received input signal and applies this signal to the receiver output.

(2) Equal-gain Combiner: The equal-gain combiner adds the input signals and applies the sum to the receiver output.

(3) Maximal-ratio combiner: The maximal-ratio or ratio-square combiner squares the input signals before addition and then applies the sum to the receiver output.

c. The probability of fade outage (P_o) for tropo and diffraction paths can be estimated for the three types of combiners (selection, equal-gain, and maximal-ratio).

(1) For selection combining:

$$P_o = \left[1 - \exp\left(-10^{-F/10}\right)\right]^M \tag{33}$$

where

P_o = the probability of fade outage

F = the fade margin (dB)

M = the number of diversity channels

NOTE: M = 1, for non-diversity

= 4, dual-diversity (frequency or space)

= 8, quad-diversity

(2) For equal-gain combining:

$$P_o = \frac{(2M)^M}{(2M)!} \quad 10^{-MF/10} \tag{34}$$

(3) For maximal-ratio combining:

$$P_o = \frac{10^{-MF/10}}{M!} \tag{35}$$

1.3.2 <u>Availability Equations</u>

a. Link availability is the fraction of time (T) that the signal envelope voltage (V) will be above threshold L. Hence, link availability (A) is defined as:

$$A = 1 = P_o \tag{36}$$

(1) Link availability for selection combiners is given by:

$$A = 1 - \left[1 - \exp\left(-10^{-MF/10}\right) \right]^M \tag{37}$$

(2) Link availability for equal-gain combiners is given by:

$$A = 1 - \left[\frac{(2M)^M}{(2M)!} \quad 10^{-MF/10} \right] \tag{38}$$

(3) Link availability for maximal-ratio combiners is given by:

$$A = 1 - \left[\frac{10^{-MF/10}}{M!} \right] \tag{39}$$

For convenient reference, the availability equations are presented in summary form in figure 1-7.

1.3.2.1 <u>Baseline Link Availability</u>

a. As with LOS links, the baseline link availability (A_S) is the link availability when no jamming is present. It is calculated with the appropriate availability equation (see fig. 1-7) and appropriate link parameters. The link fade margin, with no jamming present (F_S) is the difference between S_{REC} (dBm) and S_{REQ} (dBm); that is, from equation 19:

$$F_S = S_{REC} - S_{REQ} \text{ (dB)}$$

1. Selection combiner:

$$A = 1 - \left[1 - \exp\left(-10^{-F/10}\right) \right]^M$$

2. Equal-gain combiner:

$$A = 1 - \left[\frac{(2M)^M}{(2M)!} \quad 10^{-MF/10} \right]$$

3. Maximal-ratiocombiner:

$$A = 1 - \left[\frac{10^{-MF/10}}{M!} \right]$$

where:

A = link availability
F = fade margin (dB)
M = the number of diversity channels

$$M = \begin{cases} 1, & \text{non-diversity} \\ 4, & \text{dual-diversity} \\ 8, & \text{quad-diversity} \end{cases}$$

Figure 1-7. Availability equations - tropo and diffraction.

b. The received signal level, S_{REC} (dBm), is calculated using equation 20:

$$S_{REC} = P_T + G_T + G_R - L_T - L_R - L_S \text{ (dBm)}$$

where

P_T = transmitter output power (dBm)

G_T = transmitter antenna gain (dB)

G_R = receiver antenna gain (dB)

L_T = transmitter antenna system losses (dB)

L_R = receiver antenna system losses (dB)

L_S = propagation path loss (dB)

c. Propagatic path loss (L_S) for tropo and diffraction links is calculated as follow :

(1) For troposcatter links:

$$L_S = 30 \log f - 20 \log D + F(\Theta D) + L_c + A_a \tag{40}$$

where

f = frequency (MHz)

D = path length (km)

$F(\Theta D)$ = the attenuation function (dB)

Θ = the angular distance, the angle between horizon rays in the great circle plane, and is the minimum diffraction angle, or scattering angle unless antenna beams are elevated (radians)

L_c = medium-to-aperture coupling loss (dB)

A_a = absorption by water vapor and oxygen (dB) -- discussed in detail in paragraph 1.5.1.

$F(\Theta)$ is calculated by first determining Θ by:

$$\Theta = \frac{D}{a} + \Theta_{et} + \Theta_{er} \tag{41}$$

where

a = the effective earth's radius (km)

$$= a_o \left[1 - 0.04665 \exp \left(0.005577 N_S \right) \right]^{-1}$$

$$\Theta_{et} = \frac{h_{Lt} - h_{ts}}{d_{Lt}} - \frac{d_{Lt}}{2a} \qquad (42)$$

$$\Theta_{er} = \frac{h_{Lr} - h_{rs}}{d_{Lr}} - \frac{d_{Lr}}{2a} \qquad (43)$$

N_S = the value of N at the surface of the earth

$$= N_o \exp (-0.1057\ h_S)$$

$$= \left[N_o \exp (0.1057\ h_{st}) + N_o \exp (-0.1057\ h_{sr}) \right] /2 \qquad (44)$$

a_o = 6370 km

N_o = surface refractivity reduced to sea level (see fig. 1-8)

h_s = elevation of the surface of the ground above mean sea level (km)

h_{st} = h_s of the transmitter site (km)

h_{sr} = h_s of the receiver site (km)

h_{Lt} = height of the transmitter horizon obstacle above mean sea level (km)

h_{Lr} = height of the receiver horizon obstacle above mean sea level (km)

h_{ts} = height of transmitter antenna above mean sea level (km)

h_{rs} = height of receiver antenna above mean sea level (km)

d_{Lt} = great circle distance from the transmitter antenna to its horizon (km)

d_{Lr} = great circle distance from the receiver antenna to its horizon (km)

Figure 1-9 shows the scatter volume and path geometry. F(ΘD) can then be calculated as follows:

For $0.01 \leq \Theta D < 10$:

$$F(\Theta D) = 139.5 + 0.06\ N_S - 2.4 \times 10^{-4}\ N_S^2 + 0.34\ \Theta D + 30 \log (\Theta D) \qquad (45)$$

For $10 \leq \Theta D < 70$:

(Text continued on page 1-24)

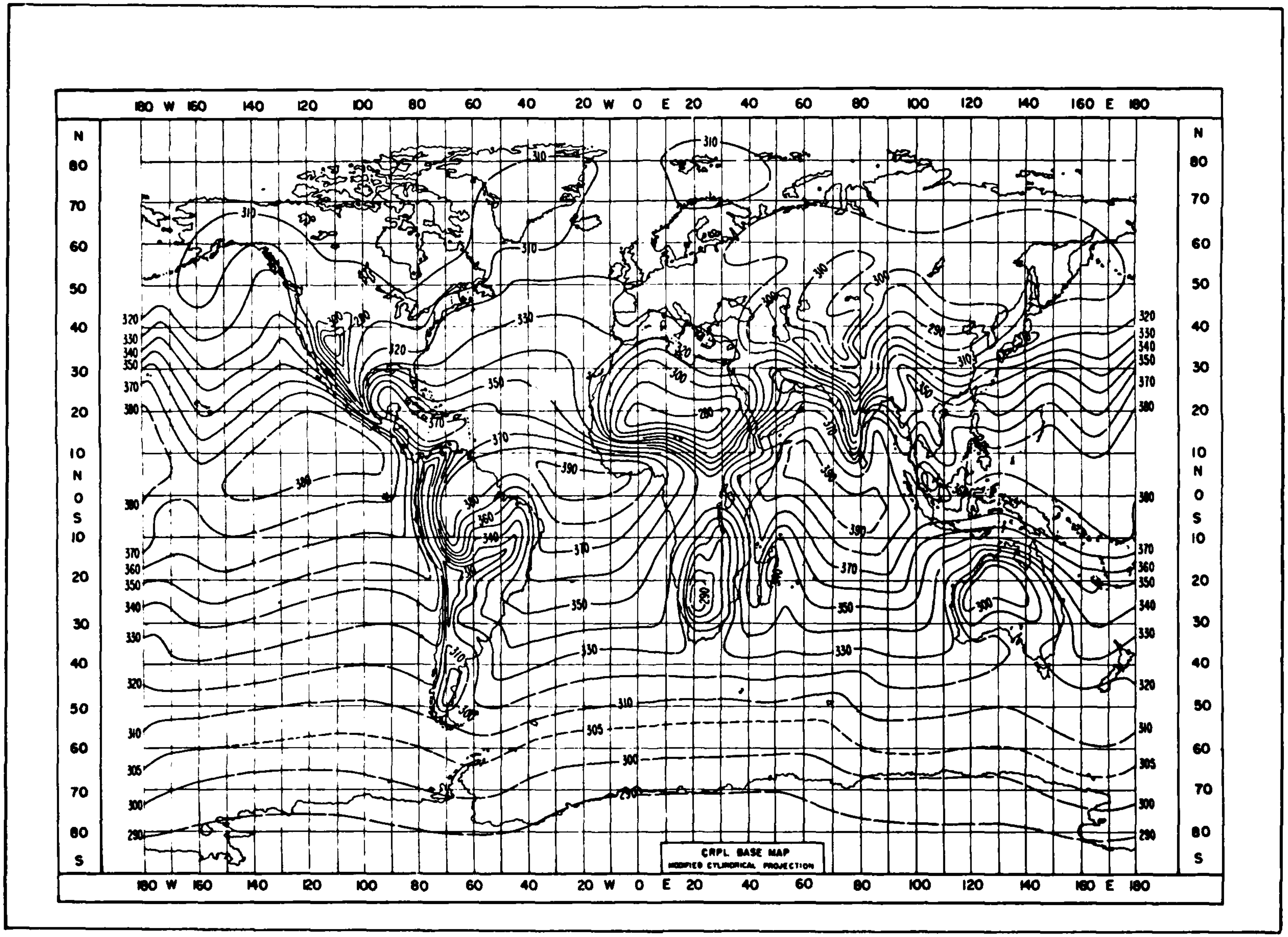


Figure 1-8. Minimum monthly surface refractivity values referred to mean sea level.

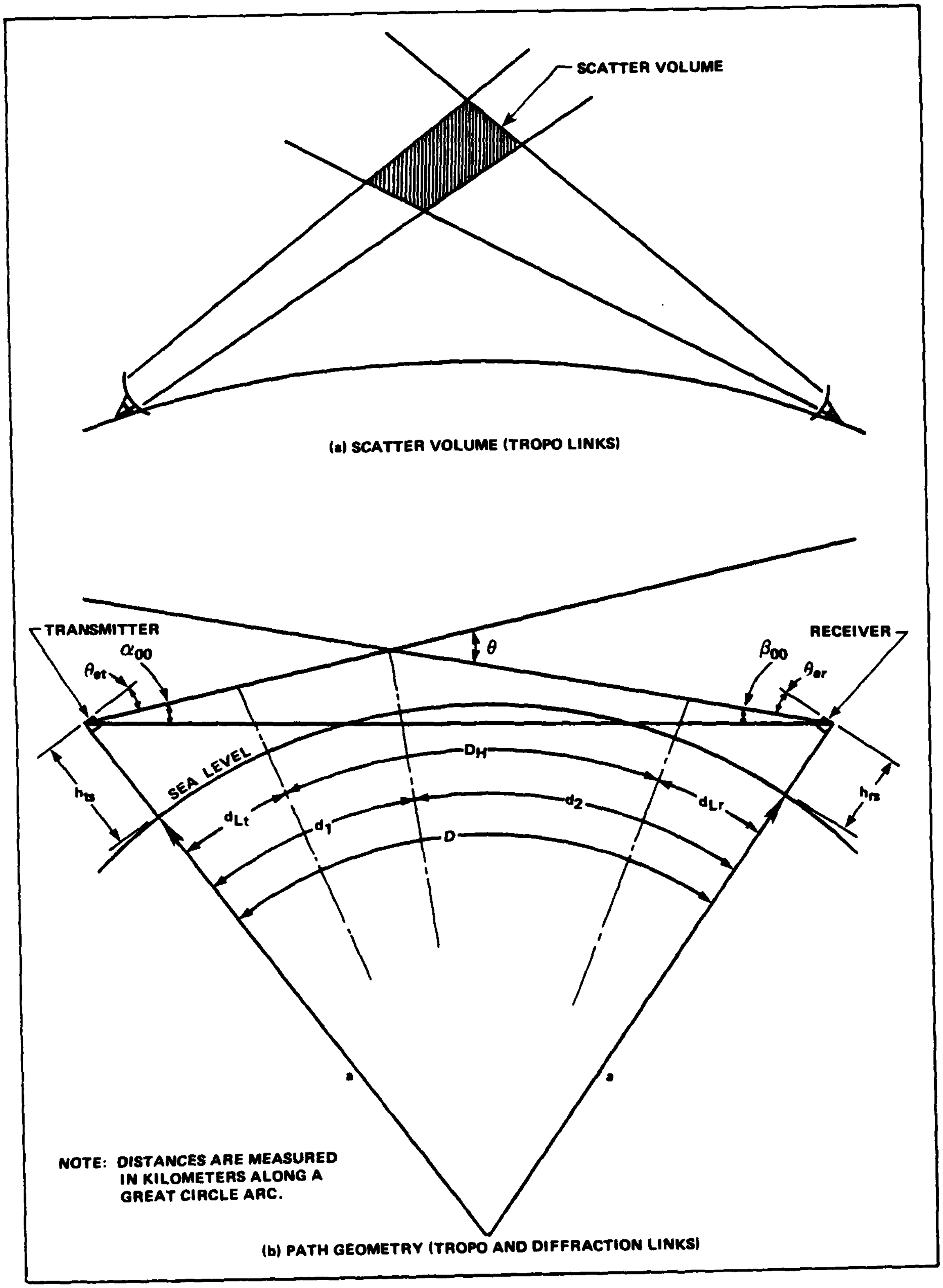


Figure 1-9. Scatter volume and path geometry.

$$F(\Theta D = 140.7 + 0.06\, N_s - 3.2 \times 10^{-4}\, N_s^{\,2} \tag{46}$$
$$+\ \Theta D\ (3.925 + 3.3 \times 10^{-3}\, N_s - 1.9 \log N_s)$$
$$+\ (22.5 + 0.05\, N_s) \log (\Theta D)$$

For $\Theta D \geq 70$:

$$F(\Theta D) = 123.6 - 0.008\, N_s + 0.158\, \Theta D + 44 \log (\Theta D) \tag{47}$$

The medium-to-aperture coupling loss (L_c) can be determined from figure 1-10. To convert the scatter angle (Θ) from radians to degrees, multiply by 57.29578. To calculate the antenna 3-dB beamwidth (BW), use the following equation:

$$BW = \frac{68{,}700}{f \times d} \tag{48}$$

where

BW = antenna 3-dB beamwidth (degrees)

f = frequency (MHz)

d = diameter of parabola (ft)

(2) For diffraction links, the propagation loss (L_s) is given by:

$$L_s = 97 + 20 \log f - 20 \log D + A_D + A_a \tag{49}$$

where

f = frequency (GHz)

D = path length (statute miles)

A_D = the attenuation due to diffraction (dB)

A_a = absorption by water vapor and oxygen (dB) (discussed in detail in paragraph 1.5.1)

(a) The attenuation due to diffraction, with no ground reflections, can be determined by first calculating the parameter, V:

$$V = \pm\, 2.583\, \Theta \sqrt{(f d_1 d_2)/D} \tag{50}$$

where

f = frequency (MHz)

d_1 = the distance from the obstacle to the transmitter (km)

d_2 = the distance from the obstacle to the receiver (km)

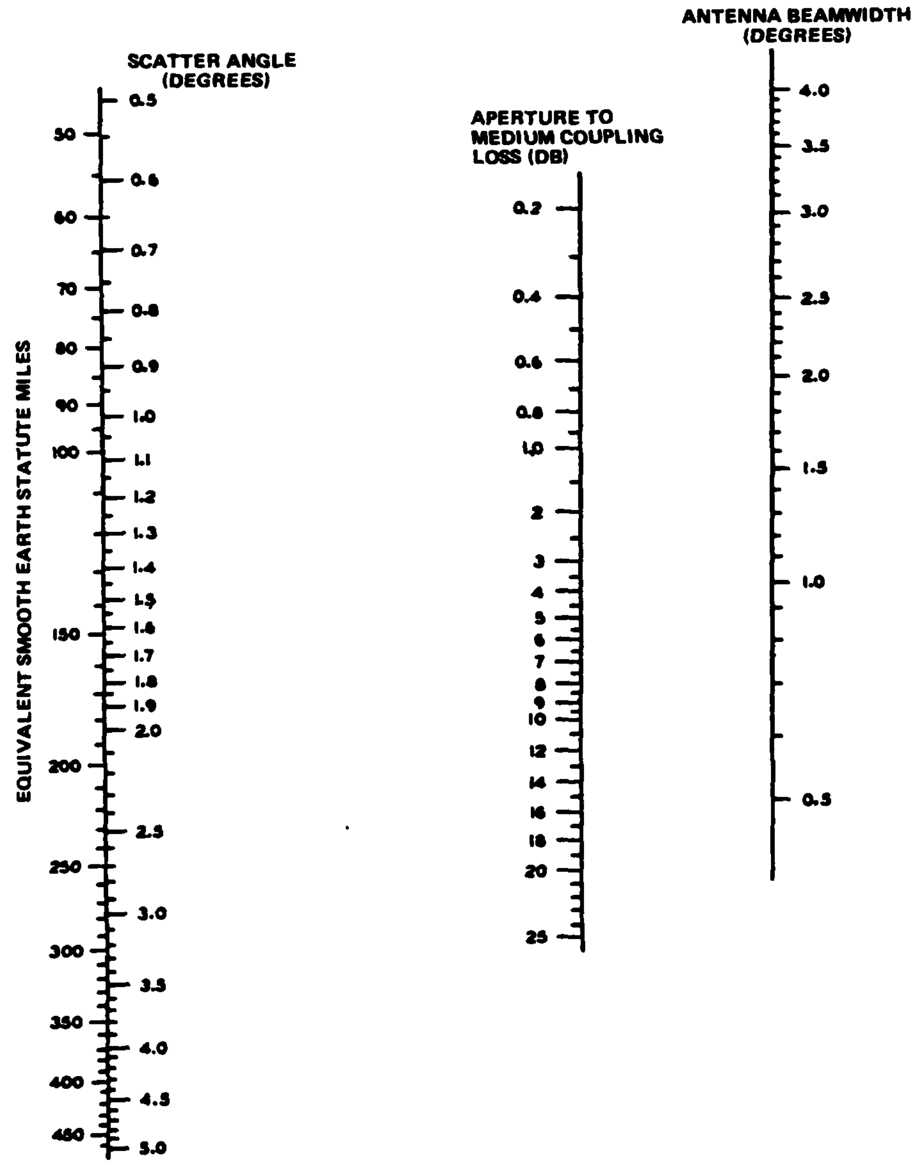


Figure 1-10. Aperture-to-medium coupling loss.

D = path length (km)

(b) The geometry for knife-edge and rounded obstacle diffraction is shown in figure 1-11.

(c) For the case of a single isolated knife-edge obstacle, A_D can be determined by calculating $A(V,0)$ ($A_D = A(V,0)$):

For $-1 \leq V \leq 0$:

$$A(V,0) = 2.78\,V^2 + 9.95V + 6.17 \tag{51}$$

For $0 \leq V \leq 3$:

$$A(V,0) = 6.08 - 0.005\,V^4 + 0.159\,V^3 - 1.7\,V^2 + 9.3V \tag{52}$$

For $V > 3$:

$$A(V,0) = 12.953 + 20 \log V \tag{53}$$

(d) For the case of a single isolated, rounded obstacle, A_D is expressed by the following equation:

$$A_D = A(V,0) + A(0,p) + U(Vp) \tag{54}$$

where

$A(V,0)$ = the diffraction loss for a knife-edge obstacle (dB), as shown above (equations 51 through 53)

$A(0,p)$ = the diffraction loss for $\Theta = 0$ over a rounded obstacle (dB)

$U(V,p)$ = the diffraction parameter which accounts for values of Θ other than zero (dB)

(e) To calculated A_D, the parameter, p, must first be determined by:

$$p = 0.676\, r^{1/3}\, f^{-1/6} \left[D / (r_1 r_2) \right]^{1/2} \tag{55}$$

where

p = the index of curvature for the crest radius of the rounded obstacle

r = the crest radius of the rounded obstacle (km)

r_1 = the distance from the transmitter to the rounded obstacle (km)

r_2 = the distance from the receiver to the rounded obstacle (km)

NOTE: For all practical purposes $r_1 r_2$ may be replaced by $d_1 d_2$.

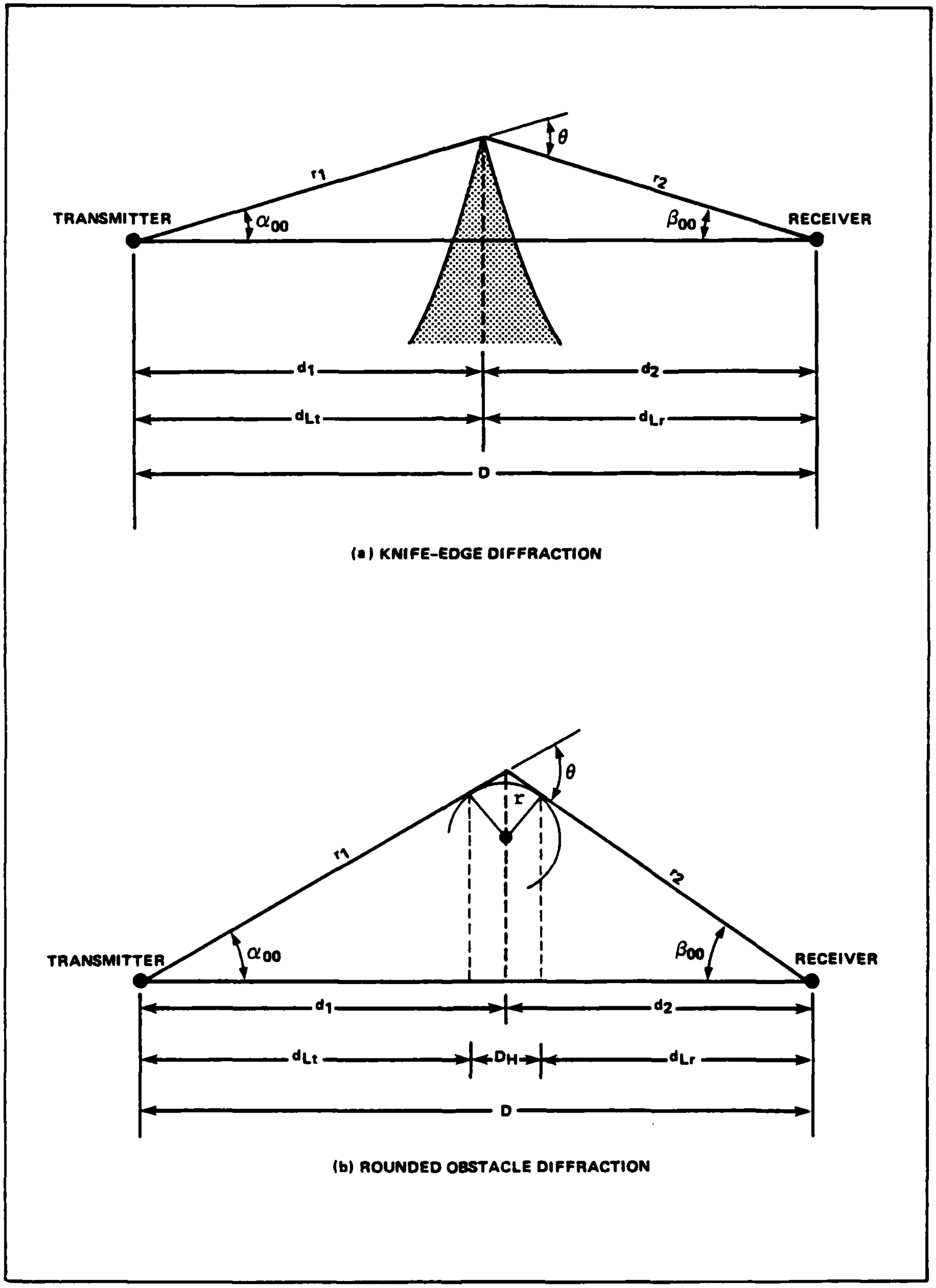


Figure 1-11. Diffraction geometery.

(f) The crest radius (r) may be calculated by:

$$r = \frac{2\ D_H\ d_{st}\ d_{sr}}{\Theta\left(d_{st}^{\ 2} + d_{sr}^{\ 2}\right)} \tag{56}$$

where

D_H = great circle distance between transmitter and receiver horizons (km)

$$D_H = D - d_{Lt} - d_{Lr} \tag{57}$$

d_{st} = distance between the transmitter antenna horizon and the crossover of horizon rays as measured at sea level (km)

$$d_{st} = D\ \beta_{oo}\ /\Theta - d_{Lt} \tag{58}$$

d_{sr} = distance between the receiver antenna horizon and the crossover of horizon rays as measured at sea level (km)

$$d_{sr} = D\ \alpha_{oo}\quad \Theta - d_{Lr} \tag{59}$$

$$\alpha_{oo} = \frac{D}{2a} + \Theta_{et} + \frac{h_{ts} - h_{rs}}{D} \tag{60}$$

$$\beta_{oo} = \frac{D}{2a} + \Theta_{er} + \frac{h_{rs} - h_{tr}}{D} \tag{61}$$

(g) With the p calculated, A(0,p) may then be calculated as:

$$A(0,p)\ 5.86 + 1.49\ p^3 + 1.46\ p^2 + 6.49\ p \tag{62}$$

NOTE: An average allowance for terrain foreground effects may be made by adding a term 10 exp (-2.3 p) to A(0,p). This term gives a correction which ranges from 10 dB for p = 0 to 1 dB for p = 1. A more detailed discussion on the effects of ground reflections may be found in reference 2, part 5.

(h) And, finally, U(V,p) may be calculated; for $Vp < 2$:

$$U(V,p) = (43.6 + 23.5\ Vp)\ \log\ (1 + Vp) - 6 - 6.7\ Vp \tag{63}$$

for $Vp \geq 2$:

$$U(V,p) = 22\ Vp - 20\ \log\ (Vp) - 14.13 \tag{64}$$

(4) S_{REQ} (dBm) can be calculated by equation 22:

$$S_{REQ} = -\ 138.6 + 10\ \log\ T + 10\ \log\ B + NF + S/N_{REQ}$$

where

T = system operating temperature in degrees Kelvin (for tropo and diffraction links T = 290°K)

B = receiver IF 3-dB bandwidth (MHz)

NF = receiver system noise figure (dB)

S/N_{REQ} = signal-to-noise ratio required to produce acceptable system output (dB), (for tropo and diffraction links S/N_{REQ} = 10 dB).

1.3.2.2 Link Availability in the Presence of Jamming

a. A_J is calculated using the appropriate equation of figure 1-8. The link fade margin in the presence of jamming (F_J) is the difference between S_{REC}(dBm) and J_{REC} (dBm), that is, per equation 23:

$$F_J = S_{REC} - J_{REC} \text{ (dB)}$$

b. J_{REC} (dBm), is calculated by equation 24:

$$J_{REC} = ERP_J + G_{RJ} - L_R - L_J + 10 \log B - 10 \log B_J$$

where

ERP_J = jammer effective radiated power (dBm)

G_{RJ} = receiver antenna gain in the direction of the jammer (dB)

B_J = jammer emission 3-dB bandwidth (MHz)

L_J = propagation path loss between jammer and link receiver (dB)

c. L_J is calculated by equation 25:

$$L_J = 97 + 20 \log f + 20 \log D + A_a$$

where

f = frequency (GHz)

D = D_J = the path length between jammer and link receiver (statute miles)

A_a = absorption by water vapor and oxygen (dB) -- discussed in more detail in paragraph 1.5.1.

1.3.3 Failure Threshold. The failure threshold is the value of fade margin below which the link is considered to be below the DCA availability criterion.

1.3.3.1 DCA Troposcatter and Diffraction Link Availability Criterion. The criterion availability value for DCS tropo and diffraction links is 0.99985, as given in TR-12-76. This criterion value is denoted A_C for the purposes of this study.

1.3.3.2 Required Jamming Margin. The fade margin required in the presence of jamming (F_C) is the S/J in dB required to restore the link to the DCA availability criterion (A_C). The calculation of F_C for tropo and diffraction links is dependent upon the type of combining employed by the specific system.

a. For selection combining:

$$F_C = -10 \log \left[-\ln \left(1 - \sqrt[M]{1 - A_C} \right) \right] \tag{65}$$

where

M = the number of diversity channels

A_C = the DCA link availability criterion

b. For equal-gain combining:

$$F_C = -10 \log \left[\sqrt[M]{\frac{(2M)!}{(2M)^M} \left(1 - A_C \right)} \right] \tag{66}$$

c. For maximal-ratio combining:

$$F_C = -10 \log \left[\sqrt[M]{M! \left(1 - A_C \right)} \right] \tag{67}$$

1.3.3.3 Required Processing Gain. The required processing gain (G_p, in dB) is the amount of ECCM required to restore the link to criterion A_C. Required G_p is given by equation 30:

$$\text{Required } G_p = F_C - F_J \text{ (dB)}$$

1.3.4 Sample Calculations

a. Presented herein are sample calculations for a typical tropo link. The tropo link selected for this example is link T1225 between Yaedake, Okinawa, and Chiran, Japan.

b. Tropo link T1225 between Yaedake and Chiran employes the NEC model TO-2G120-2A transmitters and RO-2GA60-1A receivers with frequency diversity operation and selection combining. However, in the interest of brevity, calculations will be performed for only one of the frequency pair on the link from Chiran to Yaedake.

1.3.4.1 Baseline Link Availability

a. The fade margin (F_S) was calculated using equations 19 and 20:

$$F_S = S_{REC} - S_{REQ} \text{ (dB)} \qquad (19)$$

$$S_{REC} = P_T + G_T + G_R - L_T - L_R - L_S \text{ (dBm)}$$

(1) The parameters for link T1225 operating at 1.752 GHz are:

P_T = 73.0 dBm

G_T = 48.2 dB

G_R = 48.2 dB

L_T = 0.9 dB

L_R = 0.9 dB

L_S = 236.9 dB

S_{REC} = 73 + 48.2 + 48.2 - 0.9 - 0.9 - 236.9

= - 69.3 dBm

(2) The L_S was calculated by equation 40:

$$L_S = 30 \log f - 20 \log D + F(\Theta D) + L_c + A_a$$

(3) The parameters for link T1225 are:

f = 1752 MHz

D = 360 miles = 579 km

Θ = 0.0467 radians = 2.68 degrees

h_{st} = 1625 ft = 0.5 km

h_{sr} = 1368 ft ≈ 0.42 km

BW = 0.63 degrees

N_s = 305

(4) Since ΘD = 27, $F(\Theta D)$ is calculated by equation 46:

$$F(\Theta D) = 140.7 + 0.06\ N_s - 3.2 \times 10^{-4}\ N_s^{\ 2}$$
$$+ \Theta D\ (3.925 + 3.3 \times 10^{-3}\ N_s - 1.9 \log N_s)$$
$$+ (22.5 + 0.05\ N_s) \log \Theta D$$
$$F(\Theta D) = 140.7 + 0.06\ (305) - 3.2 \times 10^{-4}\ (305)^2$$
$$+ (27\ (3.925 + 3.3 \times 10^{-3}\ (305) - 1.9 \log 305)$$
$$+ (22.5 + 0.05\ (305))\ \log 27$$
$$F(\Theta D) = 140.7 + 18.3 - 29.8 + 0.225 + 52.9$$
$$F(\Theta D) = 182.3 \text{ dB}$$

(5) The medium-to-aperture coupling loss (L_c) is obtained from figure 1-10, where Θ = 2.68 degrees and BW = 0.63 degrees. Hence, L_c = 12 dB.

(6) Absorption by water vapor and oxygen (A_a) is calculated using the methods of paragraph 1.5.1. For this link, A_a = 0.6 dB.

(7) The propagation path loss can now be determined, using equation 40:

$$L_s = 30 \log (1752) - 20 \log (579) + 182.3 + 12 + 0.6$$
$$L_s = 97.3 - 55.3 + 182.3 + 12 + 0.6$$
$$L_s = 236.9 \text{ dB}$$

(8) The S_{REQ} for the RO-2GA60-1A receiver was estimated to be -89 dBm, by equation 22:

$$S_{REQ} = -138.6 + 10 \log T + 10 \log B + NF + S/N_{REQ}$$
$$S_{REQ} = -138.6 + 10 \log (290) + 10 \log (5) + 8.5 + 10$$
$$S_{REQ} = -138.6 + 24.6 + 7.0 + 8.5 + 10$$
$$S_{REQ} = 88.5 \approx -89 \text{ dBm}$$

(9) The fade margin (F_S) is now calculated by equation 19:

$$F_S = S_{REC} - S_{REQ} \quad \text{(dB)}$$
$$F_S = -69.3 - (-89)$$
$$F_S = 19.7 \text{ dB}$$

b. Since the RO-2GA60-1A uses selection combining at baseband (post-detection), the baseline availability can be calculated by the first equation of figure 1-7:

$$A_s = 1 - \left[1 - \exp\left(- 10^{-F_S/10}\right)\right]^M$$

in this case M = 4,

$$A_s = 1 - \left[1 - \exp\left(- 10^{-19.7/10}\right)\right]^4$$

$$A_s = 1 - \left[1 - \exp\left(- 0.010716\right)\right]^4$$

$$A_s = 1 - (1 - 0.98934)^4$$

$$A_s = 1 - 1.2913 \times 10^{-8}$$

$$A_s = 0.9999999$$

1.3.4.2 Link Availability in the Presence of Jamming

a. Consider link T1225 operating in the presence of a hypothetical airborne noise jammer at a distance of 10 miles from the receiver at Yaedake.

b. The fade margin is calculated by equation 23:

$$F_J = S_{REC} - J_{REC} \text{ (dB)}$$

c. The received jamming signal level, J_{REC} (dBm), is calculated by equation 24:

$$J_{REC} = ERP_J + G_{RJ} - L_R - L_J + 10 \log B - 10 \log B_J$$

The parameters used are:

ERP_J = 70 dBm

G_{RJ} = 28.2 dB

L_R = 0.9 dB

L_J = 122.0 dB at 1.752 GHz

B = B_J = 5 MHz

Thus,

$$J_{REC} = 70 + 28.2 - 0.9 - 122.0 + 7.0 - 7.0$$

$$J_{REC} = 24.7 \text{ dBm}$$

d. The fade margin (F_J) is:

$$F_J = S_{REC} - J_{REC}$$

$$F_J = -69.3 - (-24.7)$$

$$F_J = -44.6 \text{ dB}$$

e. The availability in the presence of jamming (A_J) is calculated by the same equation as for the baseline availability for this link:

$$A_J = 1 - \left[1 - \exp\left(- 10^{-F_J/10}\right)\right]^M$$

$$A_J = 1 - \left[1 - \exp\left(- 10^{-(-44.6)/10}\right)\right]^4$$

$$A_J = 1 - \left[1 - \exp\left(- 10^{4.46}\right)\right]^4$$

$$A_J = 1 - \left[1 - \exp(- 28840)\right]^4$$

$$A_J = 1 - (1 - 0)^4$$

$$A_J = 0$$

1.3.4.3 <u>Failure Threshold</u>

a. Comparison of the calculated A_J to the DCA link availability criterion (A_C) reveals that link T1225 is vulnerable to this jammer; that is, $A_J = 0$ and $A_C = 0.99985$, hence $A_J < A_C$.

b. The r^quired jamming margin (F_C) for link T1225 is calculated using equation (or selection combining:

$$F_C = -10 \log \left[-\ln \left(1 - \sqrt[M]{1 - A_C} \right) \right]$$

$$F_C = -10 \log \left[-\ln \left(1 - \sqrt[4]{1 - 0.99985} \right) \right]$$

$$F_C = -10 \log \left[-\ln \left(1 - \sqrt[4]{1.5 \times 10^{-4}} \right) \right]$$

$$F_C = -10 \log \left[-\ln \left(1 - 1.1066819 \times 10^{-1} \right) \right]$$

$$F_C = -10 \log \left[-\ln \ (0.88933181) \right]$$

$$F_C = -10 \log \left[-(-0.11728487) \right]$$

$$F_C = -10 \log \ (0.11728489)$$

$$F_C = 9.3 \text{ dB}$$

c. The required processing gain (G_p) is calculated by equation 30:

$$\text{Required } G_p = F_C - F_J$$

$$\text{Required } G_p = 9.3 - (-44.6)$$

$$\text{Required } G_p = 53.9 \text{ dB}$$

Thus, 53.9 dB of ECCM must be applied to this link to restore it to the DCA availability criterion ($A_C = 0.99985$).

1.4 Satellite Links

1.4.1 Satellite Link Availability Equation

a. Satellite links are not subjected to the same terrain, climate, and fading conditions as terrestrial LOS, tropo, or diffraction links. Fading is usually on the order of 6 dB, at worst case; hence, satellite links are designed for a 6-dB fade margin to account for multipath and scintillation loss variations. Since a satellite link is really a non-diversity LOS link with one terminal at an extremely high elevation, the non-diversity availability equation for LOS links was modified to permit calculation of satellite link availability. The non-diversity LOS availability equation (equation 15) is given as:

$$A = 1 - (a \times b \times 2.5 \times 10^{-6} \times f \times D^3 \times 10^{-F/10})$$

where

A = the link availability, or probability that the mean received signal level (S_{REC}) will be above the required signal level (S_{REQ})

a = terrain factor

b = climate factor

2.5×10^{-6} - a constant which accounts for the worst LOS fading period of the year

f = frequency (GHz)

D = distance (statute miles)

F = the fade margin (dB)

b. The expression in parenthesis in equation 15 is the probability of a fade outage (P_o). This expression must be modified so that P_o may be calculated for satellite links, as follows:

(1) The satellite threshold conditions must be defined in terms of the maximum allowable P_o and the expected depth of fade. For satellite links, the expected fade depth is 6 dB.

(2) Since factors a and b and the constant 2.5×10^{-6} do not apply to satellite links, a new constant, z, replaces them in the P_o equation, hence:

$$P_o = z \times f \times D^3 \times 10^{-F/10} \qquad (68)$$

(3) To determine the value of z, equation 68 must be rewritten, solving for z:

$$z = \frac{P_o}{f \times D^3 \times 10^{-F/10}} \qquad (69)$$

(4) To account for threshold conditions, some of the terms are redefined and equation 69 is rewritten to provide a general solution of z:

$$z = \frac{P_{oc}}{f \times D^3 \times 10^{-F_{D}/10}} \qquad (70)$$

where

P_{oc} = the threshold, or criterion, P_o

F_D = the expected fade depth (dB), normally 6dB

c. The general availability equation for satellite links can now be written as:

$$A = 1 - (z \times f \times D^3 \times 10^{-F/10}) \qquad (71)$$

(1) Equations 70 and 71 can be combined:

$$A = 1 - \left[\left(\frac{P_{oc}}{f \times D^3 \times 10^{-F_{D}/10}}\right)\left(f \times D^3 \times 10^{-F/10}\right)\right] \qquad (72)$$

or,

$$A = 1 - P_{oc} \times 10^{-F/10} \times 10^{F_{D}/10} \qquad (73)$$

where

A = the link availability, or probability that S_{REC} will be above S_{REQ}

P_{oc} = the criterion probability of fade outage (P_o)

F = the calculated fade margin (dB)

F_D = the expected fade depth (dB)

1.4.2 Baseline Link Availability. The baseline link availability (A_S) is the link availability when no jamming is present. It is calculated using equation 73 and the following procedure:

a. The link fade margin, with no jamming present (F_S), is calculated using equation 19:

$$F_S = S_{REC} - S_{REQ}$$

b. The received signal level (S_{REC}) is calculated using equation 20:

$$S_{REC} = P_T + G_T + G_R - L_T - L_R - L_S \text{ (dBm)}$$

c. Propagation path loss (L_s) is calculated, for satellite links, by the equation:

$$L_s = 98.7 + 20 \log f + 20 \log D + A_a \quad (74)$$

d. S_{REQ} can be calculated, using equation 22:

$$S_{REQ} = - 138.6 + \log T + 10 \log B + NF + S/N_{REQ} \text{ (dBm)}$$

where

T = system operating temperature in degrees Kelvin for satellite links:

(1) Uplink (satellite receiver; nominal T = 777°K; worst-case T = 1227°K

(2) Downlink (ground terminal receiver); nominal T = 424°K; worst-case T = 440°K

B = receiver IF 3-dB bandwidth (MHz)

NF = receiver system noise figure (dB)

S/N_{REQ} = signal-to-noise ratio required to produce acceptable system output (dB) (for satellite systems S/N_{REQ} = 10 dB)

1.4.3 Link Availability in the Presence of Jamming

a. The link availability when jamming is present (A_J) is calculated, using equation 73.

b. The link fade margin in the presence of jamming (F_J) is calculated, using equation 23:

$$F_J = S_{REC} - J_{REC} \text{ (dB)}$$

c. The received jamming signal (J_{REC}) is calculated using equation 24:

$$J_{REC} = ERP_J + G_{RJ} - L_R - L_J + 10 \log B - 10 \log B_J$$

d. Propagation path loss for the jammer (L_J) is calculated by equation 25:

$$L_J = 97.0 + 20 \log f + 20 \log D_J + A_a$$

where

D_J = path length between jammer and link receiver (statute miles)

1.4.4 Failure Thresholds. The failure threshold is the value of fade margin below which the link is considered to be below the DCA availability criterion.

1.4.4.1 DCA Satellite Link Availability Criteria. The criterion availability value for DCS satellite links is 0.999, as given in TR-12-76. This criterion value is denoted A_C for the purposes of this study.

1.4.4.2 Required Jamming Margin. The fade margin required in the presence of jamming (F_C), is the S/J, in dB, required to restore the link to the DCA availability criterion (A_C). The equation to calculate F_C for satellite links is:

$$F_C = F_D \text{ (dB)} \tag{75}$$

where

F_D = the expected fade depth (dB)

F_C = the fade margin (dB), between the received signal level (S_{REC}) and the received jamming signal level (J_{REC}), required to maintain the criterion availability.

1.4.4.3 Required Processing Gain. The required processing gain (G_p, in dB) is the amount of ECCM required to restore the link to the DCA availability criterion (A_C). The required G_p is calculated by equation 30:

$$\text{Required } G_p = F_C - F_J \text{ (dB)}$$

1.4.5 Sample Calculations. Presented herein are sample calculations for a typical satellite link. The link selected is the downlink between the Western Pacific (WPAC) satellite and the AN/MSC-46 terminal at Song So, Korea, link S2194.

1.4.5.1 Baseline Link Availability

a. The baseline link availability for the downlink of link S2194 is calculated using equation 73, at a frequency of 7.425 GHz.

b. The fade margin (F_S) is calculated using equations 19 and 20:

$$F_S = S_{REC} - S_{REQ} \text{ (dB)}$$

$$S_{REC} = P_T + G_T + G_R - L_T - L_R - L_S \text{ (dBm)}$$

The parameters for link S2194 (downlink) are:

P_T = 43 dBm

G_T = 30 dB

G_R = 56.9 dB

L_T = 0 dB

L_R = 0 dB

L_S = 203.2 dB

L_S is calculated by equation 74:

$$L_S = 98.7 + 20 \log f + 20 \log D + A_a \text{ (dB)} \tag{74}$$

The parameters for link S2194 are:

f = 7.425 GHz

D = 22,300 statute miles

A_a = 0.1 dB, as calculated by the method described in paragraph 1.5.1

$L_S = 98.7 + 20 \log (7.425) + 20 \log (22{,}300) + 0.1$

$L_S = 98.7 + 17.4 + 87.0 + 0.1$

L_S = 203.2 dB

Hence,

$S_{REC} = 43 + 30 + 56.9 - 0 - 0 - 203.2$

S_{REC} = - 73.3 dBm

S_{REQ} is calculated using equation 22:

$$S_{REQ} = -138.6 + 10 \log T + 10 \log B + NF + S/N_{REQ} \text{ (dBm)}$$

The parameters for link S2194 (downlink) are:

T = 440°K

B = 40 MHz

NF = 16.5 dB

S/N_{REQ} = 10 dB

Hence,

$$S_{REQ} = -138.6 + 10 \log (440) + 10 \log (40) + 16.5 + 10.0$$

$$S_{REQ} = -138.6 + 26.4 + 16.0 + 16.5 + 10.0$$

$$S_{REQ} = -69.7 \approx -70 \text{ dBm}$$

However, the AN/MSC-46 receiver has a parametric amplifier between the RF and IF stages which has a gain of 30 dB. Therefore,

$$S_{REQ} = -100 \text{ dBm}$$

The fade margin can now be calculated as:

$$F_S = S_{REC} - S_{REQ}$$

$$F_S = -73.3 - (-100.0)$$

$$F_S = 26.7 \text{ dB}$$

c. The baseline link availability (A_S) for S2194 (downlink) is calculated per equation 73 as:

$$A_s = 1 - \left(P_{oc} \times 10^{-F/10} \times 10^{F_D/10}\right)$$

for this DCS link:

$$P_{oc} = 1 - A_c = 1 - 0.999 = 0.001$$

$$F_D = 6 \text{ DB}$$

$$F_S = 26.7 \text{ dB}$$

$$A_S = 1 - (0.001 \times 10^{-26.7/10} \times 10^{6/10})$$

$$A_S = 1 - (0.001 \times 0.069252 \times 3.9808)$$

$$A_S = 1 - 2.7567 \times 10^{-4}$$

$$A_S = 0.9997243$$

1.4.5.2 <u>Link Availability in the Presence of Jamming</u>

a. Consider link S2194 (downlink) operating in the presence of a hypothetical airborne noise jammer at a distance of 10 miles from the AN/MSC-46 ground terminal at Song So. The same availability equation (equation 73) is used. However, the link availability in the presence of jamming (A_J) replaces A_S.

Hence,

$$A_J = 1 - \left(P_{oc} \times 10^{-F_J/10} \times 10^{F_D/10}\right)$$

b. The fade margin (F_J) is calculated by equation 23:

$$F_J = S_{REC} - J_{REC} \text{ (dB)}$$

J_{REC} is calculated by equation 24:

$$J_{REC} = ERP_J + G_{RJ} - L_R - L_J + 10 \log B - 10 \log B_J$$

The jamming parameters are:

ERP_J = 70.0 dBm

G_{RJ} = 16.9 dB

L_R = 0 dB

B = B_J = 40 MHz

L_J is calculated by equation 25:

$$L_J = 97.0 + 20 \log f + 20 \log D_J + A_a$$

where

f = 7.425 GHz

D_J = 10 miles

A_a = 0.1 dB, calculated by the method described in paragraph 1.5.1

L_J = 97.0 + 17.4 + 20.0 + 0.1

L_J = 134.5 dB

Hence,

J_{REC} = 70.0 + 16.9 - 0 - 134.5 + 16 - 16

J_{REC} = -47.6 dBm

F_J is then calculated as:

$$F_J = -73.3 - (-47.6)$$

$$F_J = -25.7 \text{ dB}$$

The link availability in the presence of jamming (A_J) is then calculated as:

$$A_J = 1 - (0.001 \times 10^{-(-25.7/10)} \times 10^{6/10})$$

$$A_J = 1 - (0.001 \times 371.45 \times 3.9808)$$

$$A_J = 1 - 0.3643181$$

$$A_J = 0.6356819$$

1.4.5.3 Failure Threshold. Comparison of the calculated A_J to the DCA availability (A_C) reveals that the downlink is vulnerable to the jammer (0.63561819 < 0.999).

1.4.5.4 Required Jamming Margin. The required jamming margin (F_C) is determined by equation 75:

$$F_C = F_D = 6 \text{ dB} \tag{75}$$

1.4.5.5 Required Processing Gain. The processing gain required to restore link S2194 (downlink) to the DCA availability criterion (A_C = 0.999) is calculated by equation 30:

$$\text{Required } G_p = F_C - F_J$$

$$\text{Required } G_p = 6 - (-25.7)$$

$$\text{Required } G_p = 31.7 \text{ dB}$$

Therefore, 31.7 dB of processing gain must be achieved by employing the available ECCM techniques, either singly or in combination, to restore the downlink to the DCA availability criterion.

1.5 Atmospheric Absorption. Atmospheric absorption may seriously affect LOS, tropo, diffraction, and satellite links, particularly at frequencies above 1 GHz. Atmospheric absorption is comprised of several different factors which variously influence link performance. These factors are (1) absorption by water vapor and oxygen, (2) sky-noise temperature, (3) attenuation by rain, and (4) attentuation in clouds. Since only absorption by water vapor and oxygen was considered in this study, for the sake of simplicity, it will be treated in some detail in paragraph 1.5.1 The remaining factors will be discussed briefly in subsequent paragraphs. Details on these factors may be found in reference 2, part 5.

1.5.1 Absorption by Water Vapor and Oxygen. Absorption by water vapor and oxygen affects radio links over a range of frequencies from 100 MHz to 100 GHz and may be calculated by the equation (from reference 2, part 5):

$$A_a = \gamma_{oo} \, r_{eo} + \gamma_{wo} \, r_{ew} \text{ (dB)} \tag{76}$$

where

A_a = absorption by water vapor and oxygen (dB)

γ_{oo} = the differential absorption for oxygen (dB per Km)

γ_{wo} = the differential absorption for water vapor (dB per km)

r_{eo} = the effective distance for absorption by oxygen in the atmosphere (km)

r_{ew} = the effective distance for absorption by water vapor in the atmosphere (km)

γ_{oo} and γ_{wo} can be determined for a given frequency (GHz) from figure 1-12, and r_{eo} and r_{ew} can be obtained for a given path length (km) and angle of elevation above the horizontal, Θ (radians), from figures 1-13 through 1-15. Figures 1-12 through 1-15 were extracted from reference 2, part 5.

1.5.2 Sky-Noise Temperature. The nonionized atmosphere is a source of radio noise, with the same properties as a reradiator that it has as an absorber. This reradiation is primarily due to oxygen and water vapor over the frequency range from 100 MHz to 100 GHz. Details are given in reference 2, part 5.

1.5.3 Attenuation by Rain. The attenuation of radio waves above 2 GHz by suspended water droplets and rain often exceeds the combined absorption by water vapor and oxygen. Water droplets in fog or rain will scatter radio waves in all directions, regardless of whether the drops are less than or equal to the wavelength. Attenuation is a function of rainfall rate and height above the surface of the ground. Details are given in reference 2, part 5.

1.5.4 Attenuation in Clouds. Cloud droplets are those water or ice particles having radii smaller than 100 microns (0.01 cm). Attenuation in clouds should be considered for links operating above 6 GHz in mountainous terrain. Details are given in reference 2, part 5.

1.6 Digital Considerations

a. The previous discussion of fade margin in terms of signal-to-threshold and signal-to-jamming ratios are applicable to digital as well as analog systems. Digital systems are often discussed in terms of signal energy per bit-to-noise power density ratio (E_b/N_o) or signal energy per bit-to-jamming energy per bit ratio (E_b/E_J). Hence, the following equations will permit conversion of the generalized parameters to the digital case, or vice versa.

b. E_b/N_o received, in dB, and S_{REC} (dBm), can be obtained by the equations:

$$E_b/N_{o_{REC}} \text{ (dB)} = S_{REC} - 10 \log R_b + 228.6 - 10 \log T - NF + 10 \log B \quad (77)$$

or

$$S_{REC} = E_b/N_{o_{REC}} \text{ (dB)} + 10 \log R_b - 228.6 + 10 \log T + NF - 10 \log B \quad (78)$$

where

(Text continued on page 1-49)

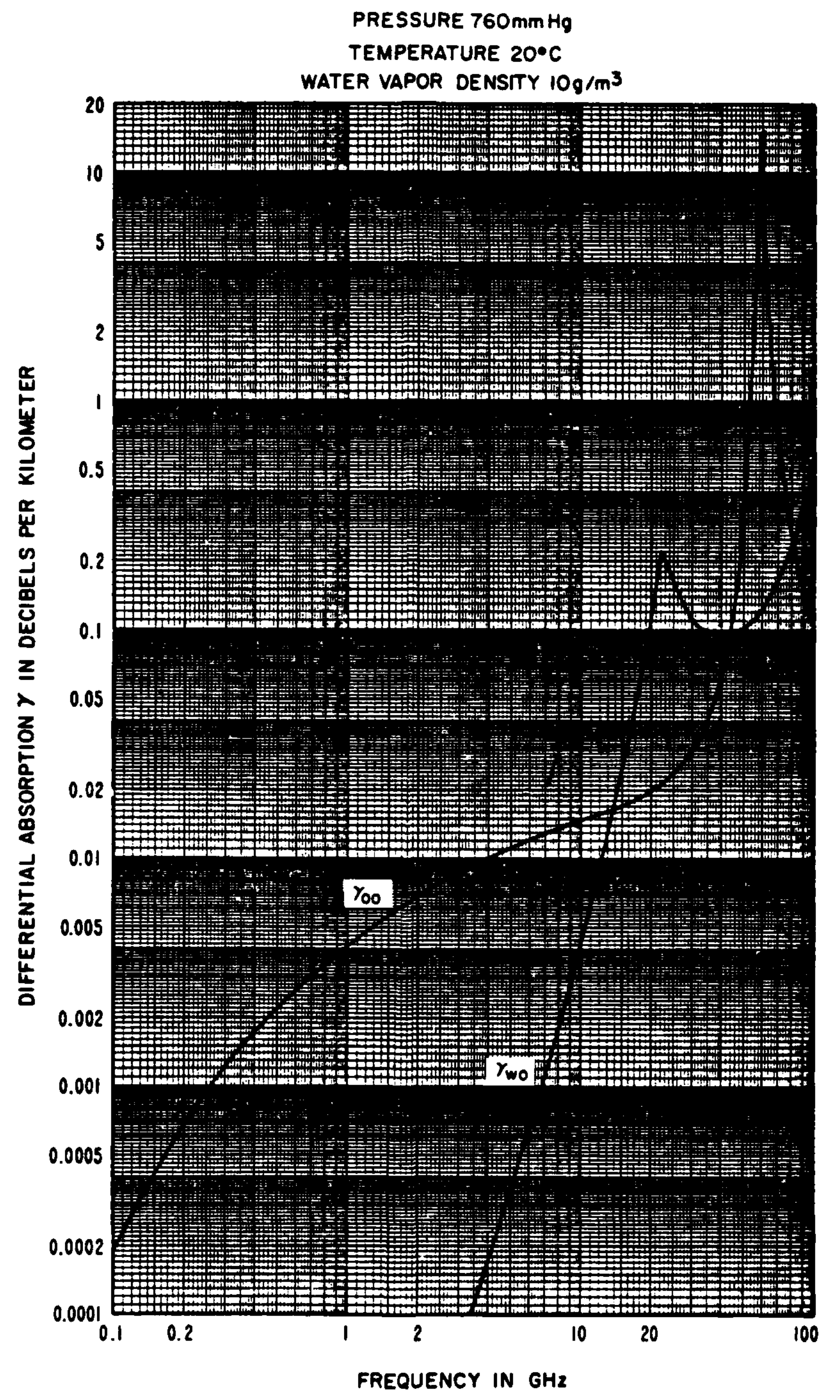
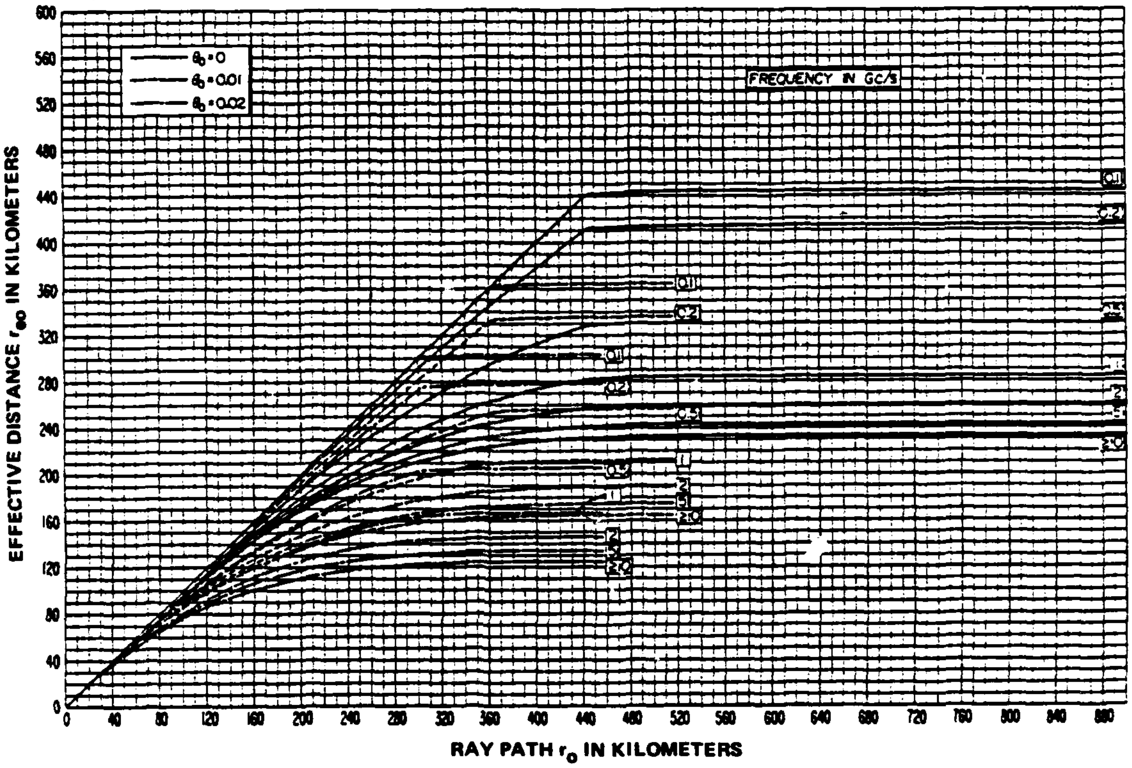


Figure 1-12. Surface values γ_{oo} and γ_{wo} of absorption by oxygen and water vapor.



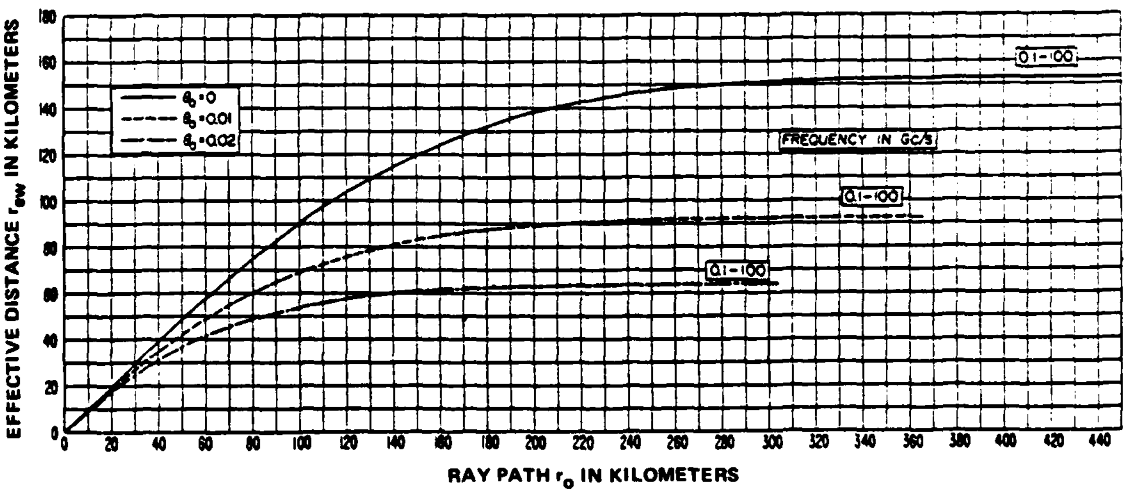


Figure 1-13. Effective distances r_{eo} and r_{ew} for absorption by oxygen and water vapor, $\theta_o = 0, 0.01, 0.02$.

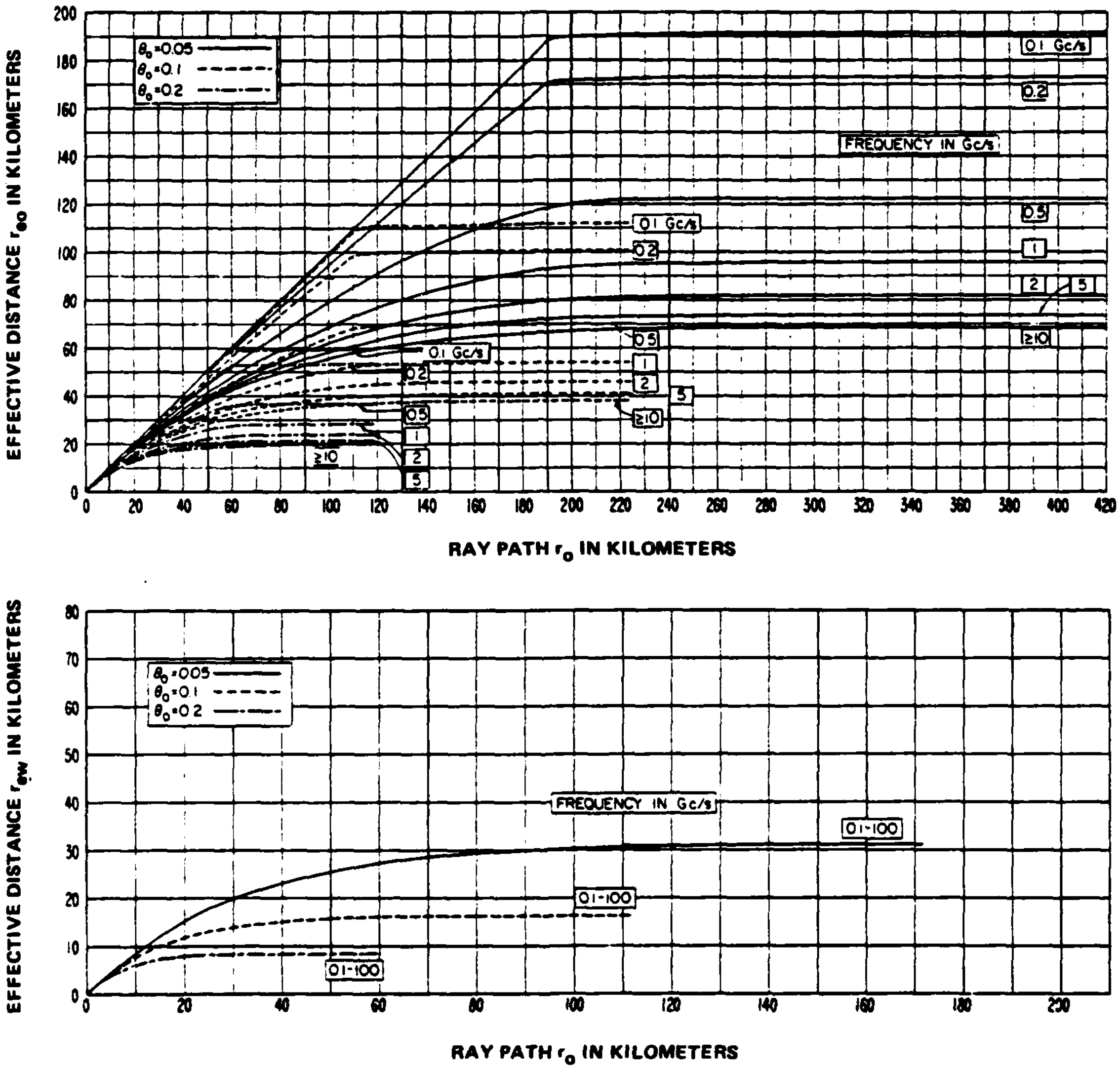


Figure 1-14. Effective distances r_{eo} and r_{ew} for absorption by oxygen and water vapor, θ_o = 0.05, 0.1, 0.2.

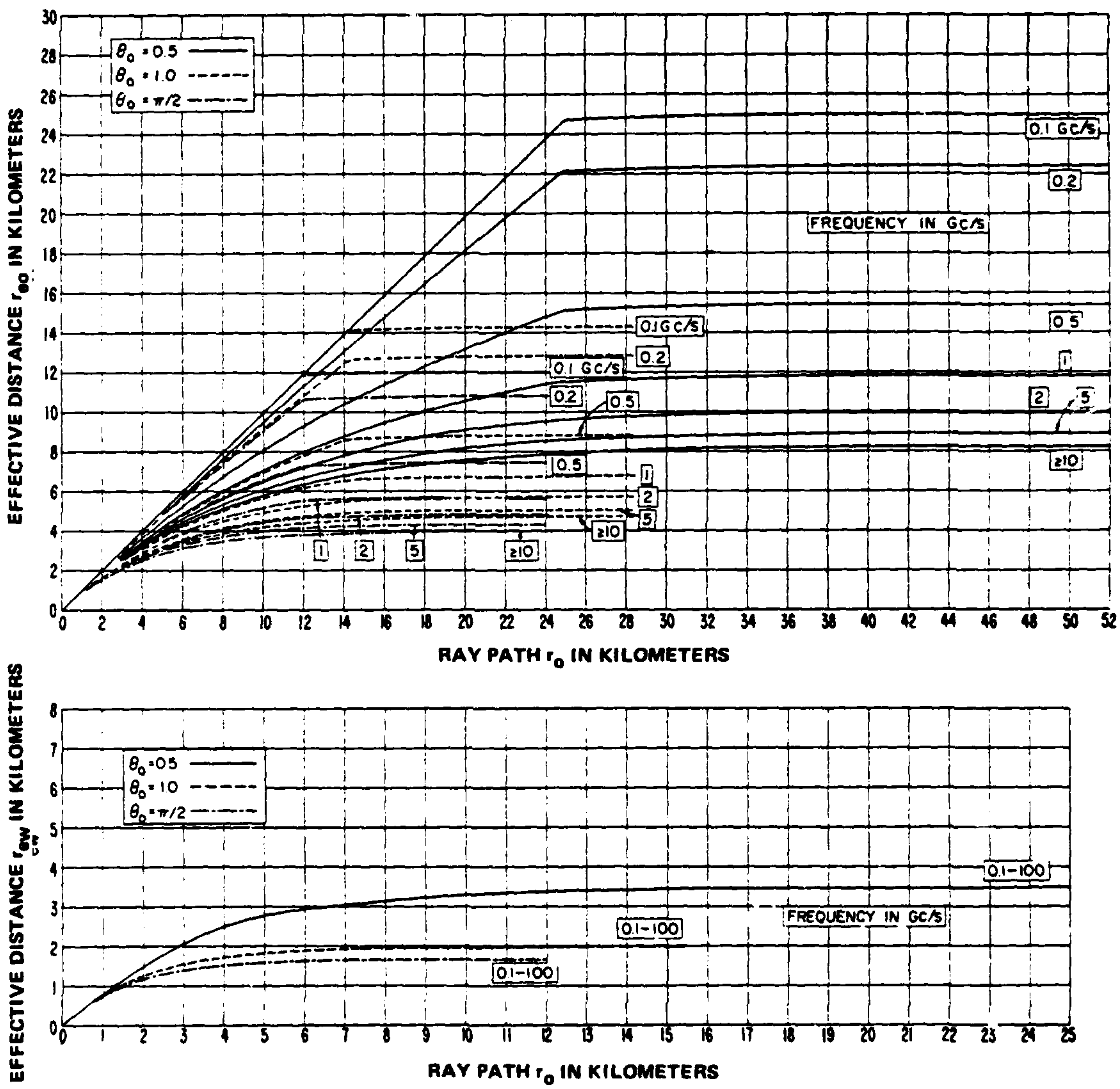


Figure 1-15. Effective distances r_{eo} and r_{ew} for absorption by oxygen and water vapor, $\theta_o = 0.5, 1, \pi/2$.

E_b = signal energy per bit [milliwatts per bit (mW/b)]

N_o = noise power density [milliwatts per Hz (mW/Hz)]

E_b/N_o (dB) = 10 log E_b/N_o (mW)

S_{REC} = mean received signal level (dBm)

R_b = the link data rate (b/s)

T = system operating temperature (degrees, Kelvin)

NF = receiver noise figure (dB)

B = receiver IF 3-dB bandwidth (Hz)

c. E_b/N_o required, in dB, and S_{REQ} (dBm), can be calabulted by the equation:

$$E_b/N_{o_{REQ}} \text{ (dB)} = S_{REQ} - 10 \log R_b + 228.6 - 10 \log T - NF + 10 \log B \qquad (79)$$

or

$$S_{REQ} = E_b/N_{o_{REQ}} + 10 \log R_b - 228.6 + 10 \log T + NF - 10 \log B \qquad (80)$$

d. The fade margin (F_S), in terms of energy per bit, can be calculated by:

$$F_S = E_b/N_{o_{REC}} - E_b/N_{o_{REQ}} \text{ (dB)} \qquad (81)$$

e. E_J/N_o received, in dB, and J_{REC}(dBm) can be obtained by the euqations:

$$E_J/N_{o_{REC}} \text{ (dB)} = J_{REC} - 10 \log R_b + 228.6 - 10 \log T - NF + 10 \log B \qquad (82)$$

or

$$J_{REC} = E_J/N_{o_{REC}} \text{ (dB)} + 10 \log R_b - 228.6 + 10 \log T + NF - 10 \log B \qquad (83)$$

where

J_{REC} = the received jamming signal level (dBm)

E_J = jamming signal energy per bit (mW/b)

N_o = noise power density (mW/Hz)

E_J/N_o(dB) = 10 log E_J/N_o (mW)

f. The fade margin (F_J), in terms of energy per bit, can be calcuated by:

$$F_J = E_b/N_{o_{REC}} - E_J/N_{o_{REC}} \text{ (dB)} \quad (84)$$

which is E_b/E_j (dB).

PART 2 - LINK QUALITY

2.1 Introduction. Discussed herein are the parameters used to measure the quality of the information transferred over a radio link and the quality of the link itself. Information quality is expressed in articulation score (AS) for voice circuits (channels) and probability of error for teletypewriter and data circuits. Link quality is expressed in terms of link availability (as discussed previously) for both analog and digital radio links and probability of error (P_e) in the mission, or aggregate, bit stream, for digital links.

2.2 Quality of Voice Circuits

a. The measure of voice quality most widely used is the AS. This is a measure of the percentage of phonetically balanced words in a test message correctly interpreted by a team of trained listeners. In practice, team members listen and respond to recordings of the test message derived from the output of a test channel into which interference has been injected. After all listeners have responded, the responses are computer-processed to determine the mean and standard deviation for the listeners.

b. A representative curve of AS versus noise interference, in terms of signal-to-interference ratio, S/I (dB), is provided in figure 2-1. This curve was used in the estimation of voice circuit quality in this study and is considered a good approximation of actual voice quality over the DCS links which were evaluated. Of course, actual measured values may vary somewhat from these estimates, but the estimated values provide a good indication of the magnitude of voice channel degradation.

2.3 Quality of Data and Teletypewriter Circuits. A measure of data or teletypewriter quality widely accepted is the P_e. P_e is a function of signal-to-noise ratio (S/N) or S/I and the type of modulation employed to transfer the data or teletypewriter message over the radio link. The majority of data modems and teletypewriters in use in the DCS employ FSK modulation and, hence, the curve in figure 2-2 was used in this study to estimate the level of degradation of data and teletypewriter circuits.

2.4 Quality of Digital Radio Links

a. The quality of digital radio links is determined by the P_e in the aggregate or mission bit stream (sometimes referred to as the baseband bit stream). P_e is a function of S/N or S/I and the type of modulation employed by the radio system. The most common modulation schemes employed (or planned for) in the DCS are pulse code modulation (PCM), phase-shift keying (PSK), three-level partial response (3LPR), quadrature partial response (QPR), and quadrature phase shift keying (QPSK).

b. Curves of P_e versus S/I are provided for the most common digital modulation schemes as follows:

(1) PCM, PSK or QPSK, figure 2-3.

(2) 3LPR, figure 2-4.

(Text continued on page 2-6)

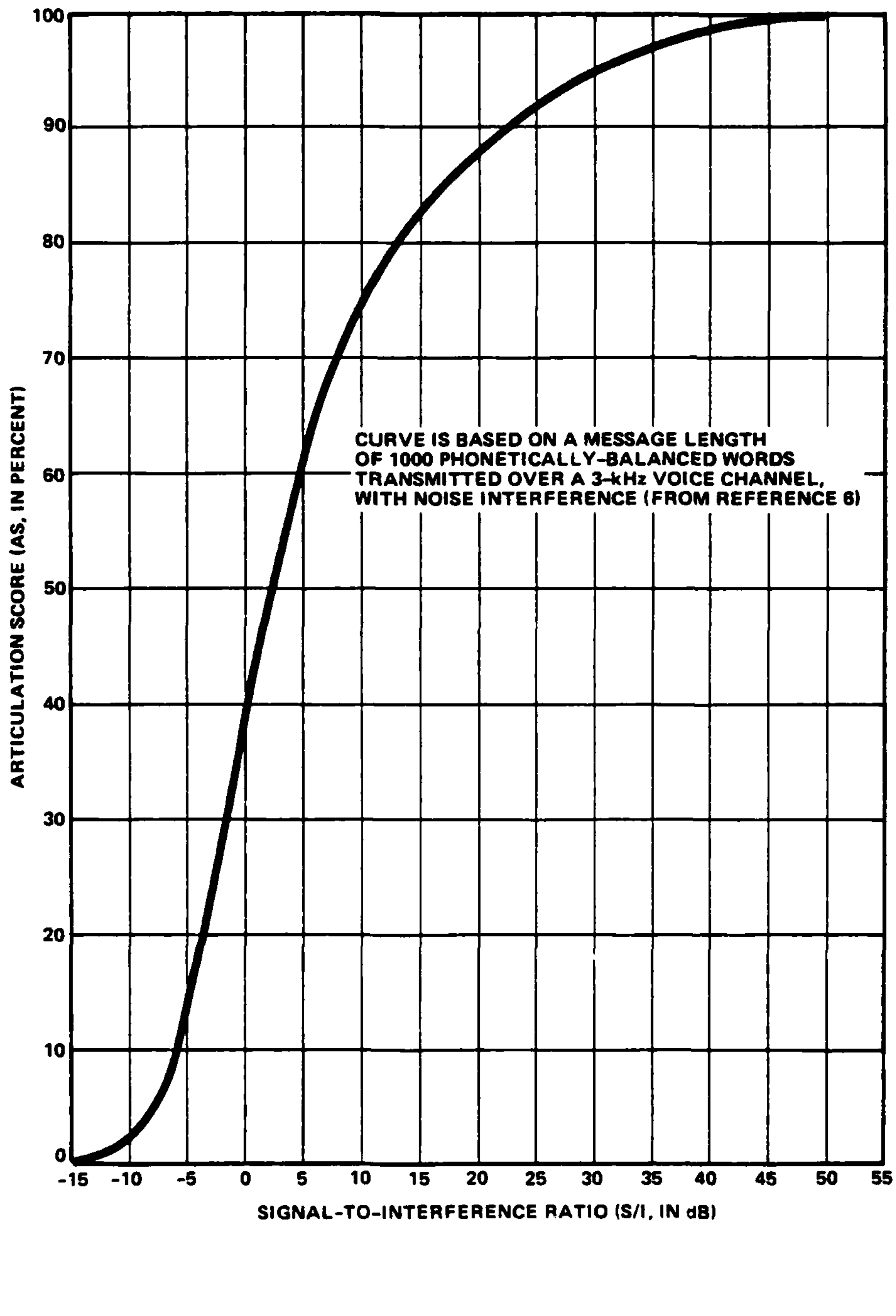


Figure 2-1. Articulation score versus noise interference.

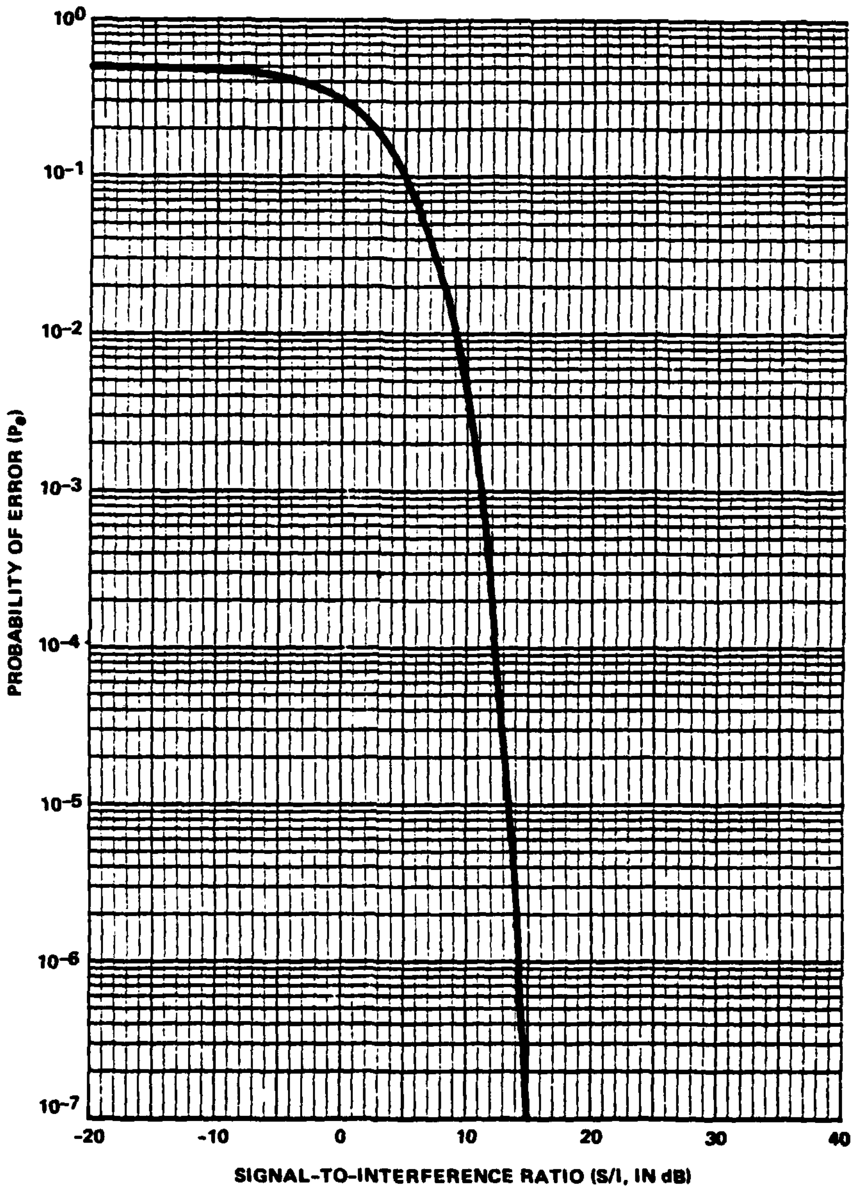
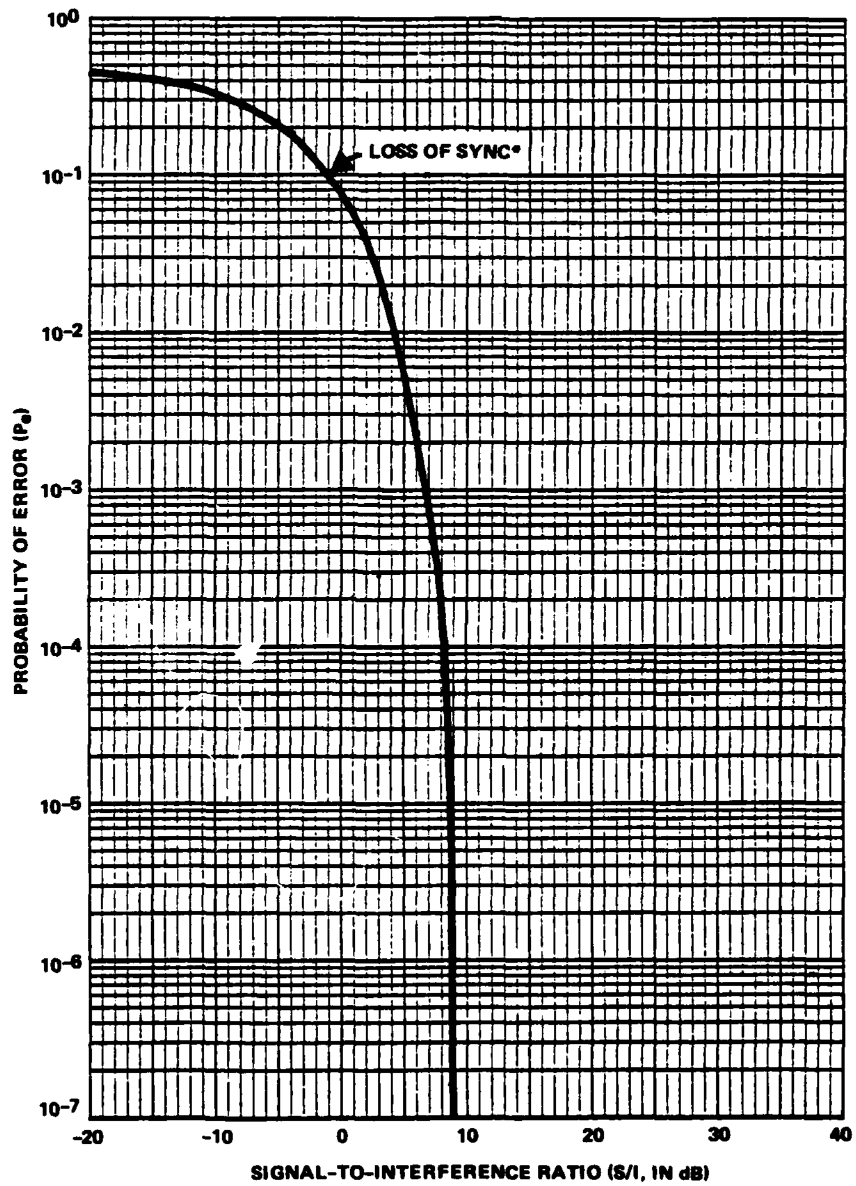


Figure 2-2. Probability of error versus signal-to-interference ratio for noncoherent FSK modulation.



*ESTIMATED.

Figure 2-3. Probability of error versus signal-to-interference ratio for PCM (polar), PSK, or QPSK modulation.

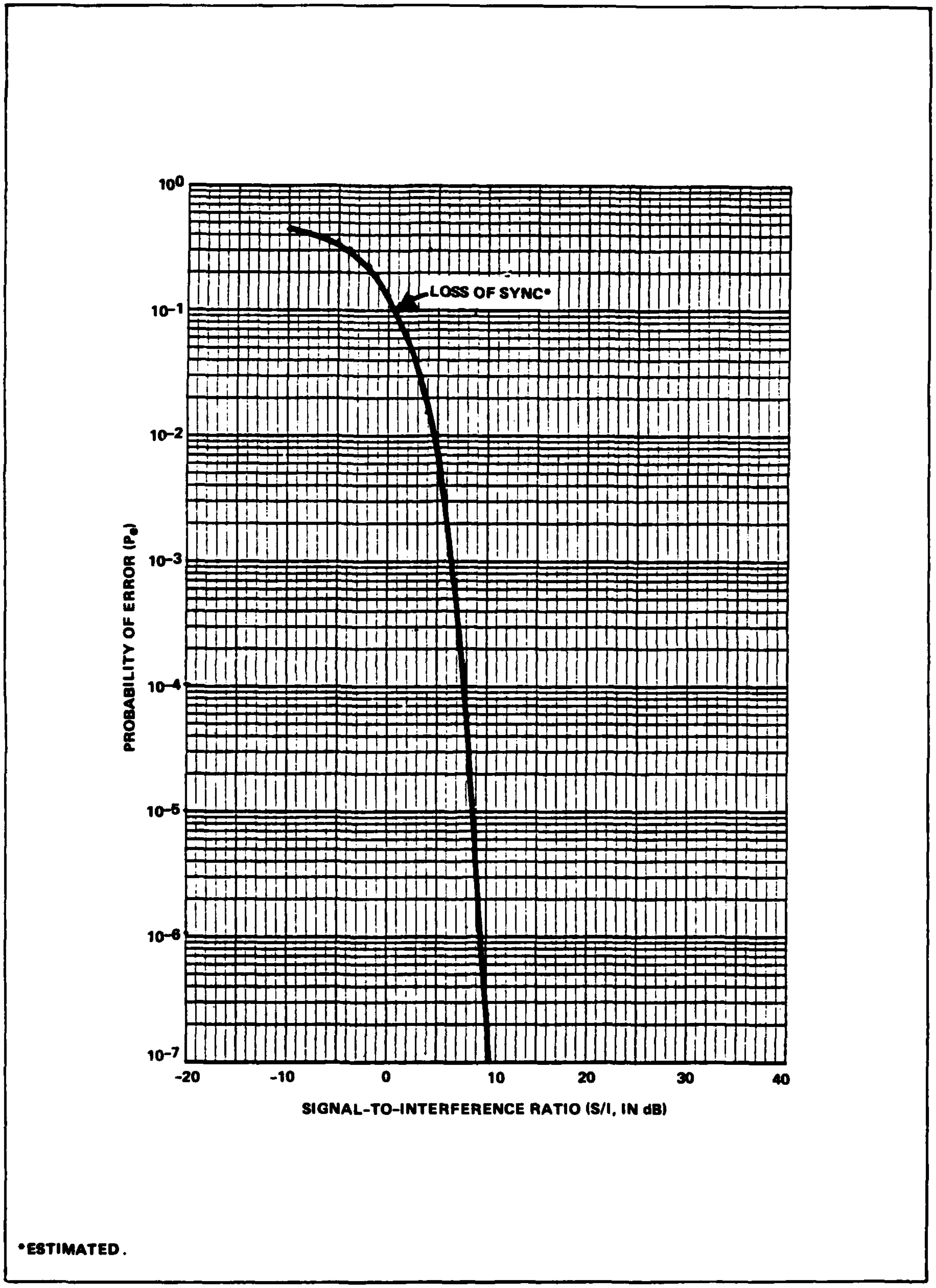


Figure 2-4. Probability of error versus signal-to-interference ratio for 3LPR modulation.

(3) QPR, figure 2-5.

2.5 Probability of Error Equations. Equations for the calculation of P_e for the modulation schemes discussed in paragraphs 2.3 and 2.4, and for other modulation schemes which may be encountered, are provided in terms of S/I (S/I, actual ratio, not in dB) in figure 2-6. It should be noted that for baseline calculations (no interference or jamming) S/I can be replaced by S/N. For jamming calculations, S/I can be replaced by S/J. It should also be realized that the equations will provide the theoretical P_e, and that actual measured P_e values may vary from the theoretical values. Figure 2-7 provides a breakout of the abbreviations for the modulations shown in figure 2-6.

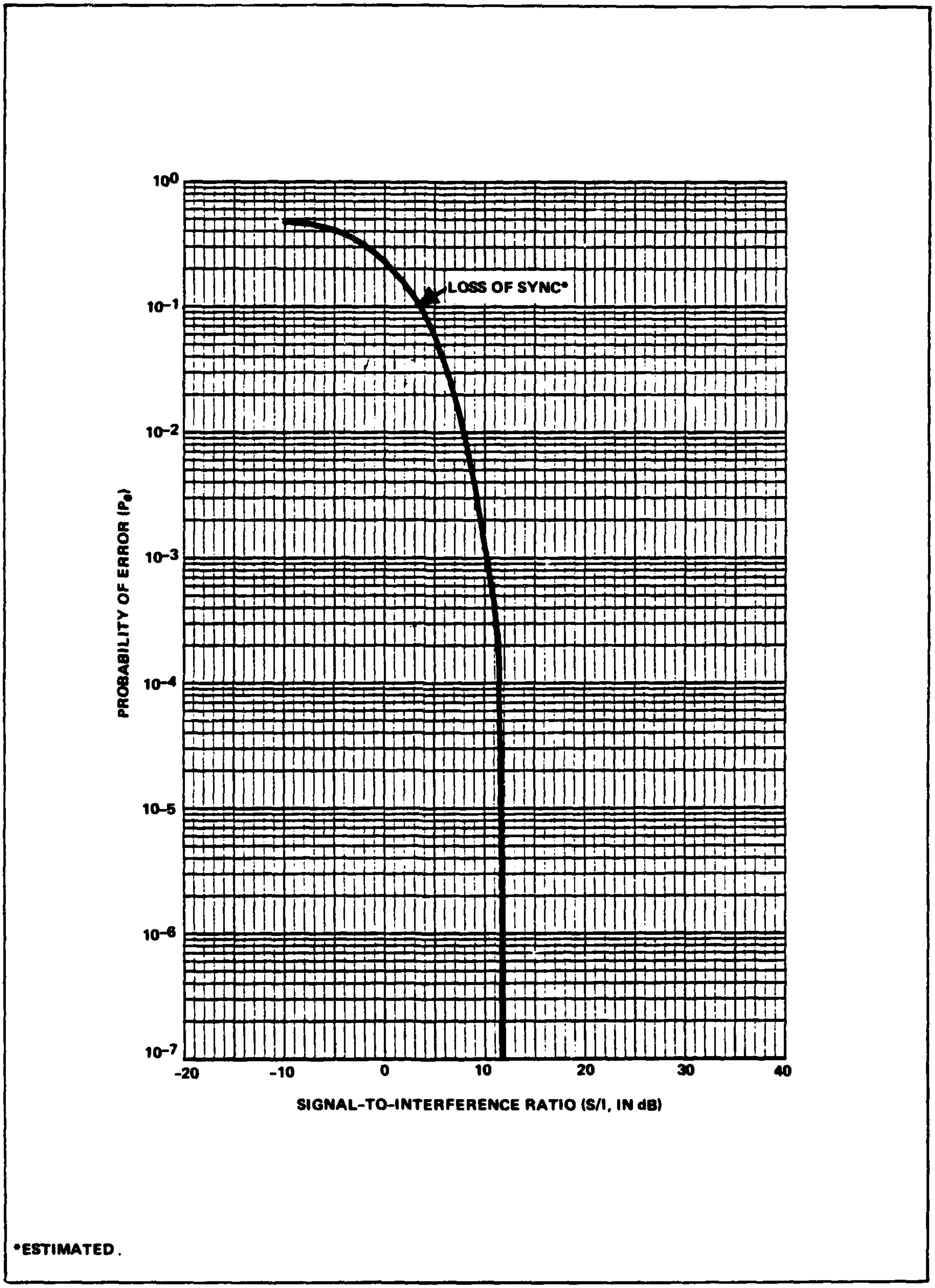


Figure 2-5. Probability of error versus signal-to-interference ratio for QPR modulation.

Modulation	Equation
• FSK (coherent) • ASK (coherent) • PCM (unipolar or NRZ)	$P_e = 0.5 \text{ erfc} \sqrt{0.5(S/I)}$
• FSK (noncoherent)	$P_e = 0.5 \exp[-0.5(S/I)]$
• PCM (polar) • PSK • QPSK	$P_e = 0.5 \text{ erfc} \sqrt{(S/I)}$
• OOK	$P_e = 0.5 \text{ erfc} \left[0.5 \sqrt{(S/I)}\right]$
• ASK (noncoherent)	$P_e = 0.5 \exp\left[-0.5(S/I)\right]\left[1 + \frac{1}{\sqrt{2\pi(S/I)}}\right]$
• QPR	$P_e = 0.75 \text{ erfc}\left[0.707\sqrt{(S/I)}\right] - 0.25 \text{ erfc}\left[2.12\sqrt{(S/I)}\right]$
• 3LPR	$P_e = 0.75 \exp[-1.5(S/I)] - 0.25 \exp[-2(S/I)]$
• DPSK	$P_e = 0.5 \exp[-(S/I)]$
• PPM	$P_e = \frac{2}{b_u t\sqrt{\pi(S/I)}} \exp[-0.5(S/I)]$

S/I = signal-to-interference ratio (not in dB), $S/I = 10^{S/I(\text{in dB})/10}$
erfc = error function complement = 1 - erf
exp = exponential function
b_u = baseband upper cutoff, or maximum, frequency (Hz)
t = pulse width (seconds)

Figure 2-6. Probability of error equations for various modulation schemes.

ASK	=	Amplitude shift keying
DPSK	=	Differential phase shift keying
FSK	=	Frequency shift keying
OOK	=	On-off keying
PCM	=	Pulse code modulation
PPM	=	Pulse position modulation
PSK	=	Phase shift keying
QPR	=	Quadrature partial response
QPSK	=	Quadrature phase shift keying
3LPR	=	Three-level partial response

Figure 2-7. Breakout of modulation abbreviations.

PART 3 - NETWORK TRAFFIC

3.1 Introduction

a. Traffic within the DCS networks consists of a wide variety of circuits provided to subscribers via several types of access. Circuit types are: (1) voice, (2) secure voice, (3) teletypewriter, (4) data, (5) facsimile, and (6) television. A subscriber is provided connection to another subscriber by the two methods--common user access lines via switchboards or exchanges and direct lines (patched directly through the switch).

b. In the case of common-user lines, many subscribers must compete for a limited, or finite, number of lines (trunks, in telephone parlance) at a switchboard, or exchange. During a busy period, a subscriber faces an increased probability of receiving an all-trunks-busy signal and, hence, must hang up and try again at a later time. This probability is also called the probability of a lost call, or the probability of blocking--that is, the call is lost or blocked from completion. The probability of a lost call during the busy period is referred to in the DCS as the grade-of-service (GOS). The DCA has established criteria for acceptable GOS within the DCS network.

c. In the case of direct-access lines, a subscriber has direct access to another subscriber with no blocking of calls. Actually, several subscribers may use the same telephone, but this factor has no impact on the network, since no blocking occurs within the system. Since there is no blocking within the system, no GOS can be calculated.

d. A network traffic analysis usually consists of (1) determining the number of circuits between telecommunications facilities (such as switches, switchboards, or exchanges); (2) the traffic load offered to these circuits (usually during the busy hour, or 2-hour period); and (3) determining the resultant GOS for both the baseline (original) and alternate routing situations. However, traffic statistics such as busy-hour offered load and average holding time were not available for this study. Therefore, the network analysis was performed for Korea and Okinawa in terms of channels (circuits) lost due to rerouting of traffic (on those links affected by ECM) over alternate routes when circuit restoration priorities (RP's) were considered. In addition, the reduction in GOS was determined for common-user circuits. The following paragraphs describe the methodology employed to accomplish this network traffic analysis.

3.2 Network Traffic Analysis

a. As previously stated, the methodology developed for this study was the result of the unavailability of traffic statistics for the DCS in the Pacific area in the form of busy-period load and average holding time. The traffic analysis for this study was performed using the procedure shown in the flow diagram of figure 3-1, and described in the following paragraphs.

b. The network traffic analysis for this study depends upon the results of the ECM and ECCM analyses. The link subjected to ECM is first evaluated to determine whether the ECM is effective in disrupting the traffic on that link. If it is not effective, there is no impact on the network traffic. If the ECM

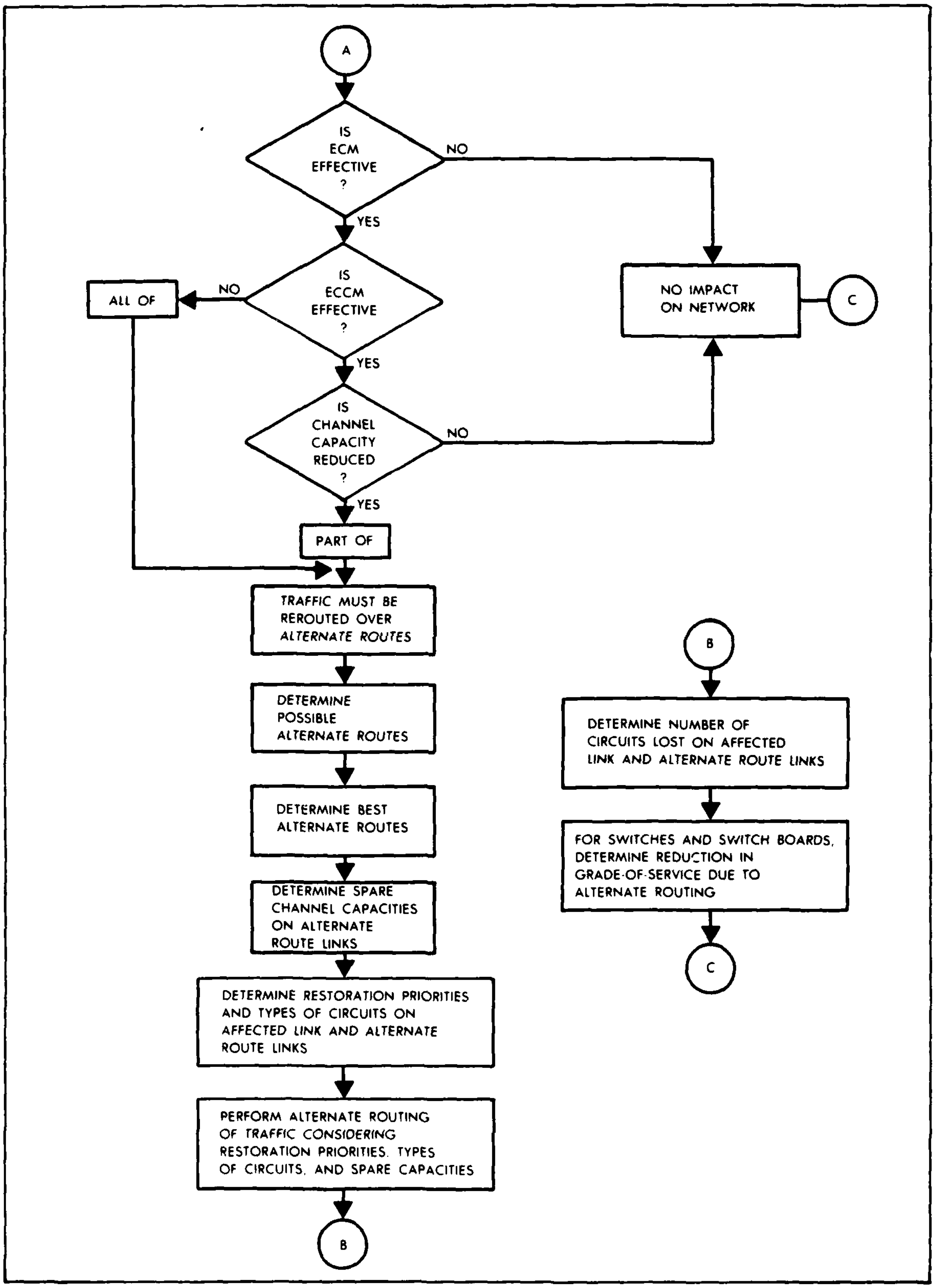


Figure 3-1. General flow of traffic analysis.

is effective, appropriate ECCM techniques are applied to the link and an evaluation is made to determine whether the ECCM is effective in restoring the link to DCA availability standards. If it is not effective, all of the traffic on that link must be rerouted over alternate routes. If the ECCM is effective, a determination is made as to whether or not the link must operate at reduced channel (circuit) capacity. If the channel capacity is not reduced, there is no impact on the network traffic. If the channel capacity is reduced, that portion of the traffic which cannot be accommodated on the link must be rerouted over alternate routes.

c. Before traffic from the affected link can be rerouted, the best alternate routes must be determined from those available in the network. Alternate routes are selected on the basis of their overall channel capacity, spare channel capacity, and the type of circuits, by RP, traversing these routes. The RP's of the circuits which must be rerouted must then be compared to the RP's of like circuits on the alternate routes. Rerouting is then accomplished by loading the reroute circuits on the alternate routes in the following order:

(1) Alternate route spare channels are loaded with reroute circuits in descending order of RP.

(2) Alternate route circuits are preempted in ascending order of RP and loaded with reroute circuits in descending order of RP. That is, RPOO circuits on the alternate routes would be preempted by RP1A circuits from the affected link, and so on. A list of RP's used by DCA is provided in figure 3-2.

d. After the traffic on the affected link has been rerouted over the alternate routes, the number of circuits (channels) lost due to preemption and/or insufficient channel capacity is determined for the affected link and the alternate route links.

e. For common-user circuits between switches, switchboards, or exchanges, the reduction in GOS is determined by the following procedure:

(1) Determine the total number of circuits between the two terminals of interest. For example, there is a total of 17 circuits between the overseas switch (OSS) at Seoul, Korea, and the AUTOVON switch (SCA) at Fuchu, Japan.

(2) Determine the traffic capacity for the total number of circuits between the two terminals for the DCA criterion GOS, using the GOS performance objective (PO) from reference 7, part 5, and the Erlang B trunk tables from reference 8, part 5. For example, the traffic capacity for the 17 circuits between Seoul OSS and the Fuchu SCA for a GOS of 0.1 (10 percent overflow) is 525 hundreds of call seconds (CCS) for the busy period.

(3) Determine the resultant number of circuits between the two terminals after alternate routing is accomplished. As a hypothetical example, alternate routing resulted in a reduction in circuits between Seoul OSS and Fuchu SCA from 17 circuits to 5 circuits.

(4) Using the capacity determined in paragraph 3.2e(2) as the offered load, the probability of a lost call (GOS) can be calculated using the Erlang B formula:

Restoration Priority (RP)	Ranking
1A	Highest
1B	
1C	
1D	
1E	
1F	
1G	
2A	
2B	
2C	
2D	
2E	
2F	
2G	
2H	
2I	
3A	
3B	
3C	
4A	
4B	
00	Lowest

Figure 3-2. DCA restoration priorities.

$$P(LC) = \frac{\frac{\ell_o^{\,n}}{n!}}{1 + \ell_o + \frac{\ell_o^{\,2}}{2!} + \ldots \frac{\ell_o^{\,n}}{n!}} \tag{1}$$

where

P(LC) = the probability of a lost call, for high-usage trunks (circuits) where a subscriber receiving a busy signal is cleared from the system (i.e., he must hang up and try later).

ℓ_o = the offered load, in erlangs = (the number of CCS)/36

n = number of trunks (circuits)

For example, in the case where the number of trunks (circuits) between the Seoul OSS and the Fuchu SCA is reduced from 17 to 5, the GOS can be calculated by inserting ℓ_o = 525 CCS = 14.58 erlangs and n = 5 as follows:

$$P(LC) = \frac{\frac{14.58^5}{5!}}{1 + 14.58 + \frac{14.58^2}{2!} + \frac{14.58^3}{3!} + \frac{14.58^4}{4!} + \frac{14.58^5}{5!}}$$

$$P(LC) = \frac{\frac{658{,}922.7}{120}}{1 + 14.58 + \frac{212.6}{2} + \frac{3099.7}{6} + \frac{45{,}193.6}{24} + \frac{658{,}922.7}{120}}$$

$$P(LC) = \frac{5491.0}{15.58 + 106.3 + 516.6 + 1883.1 + 5491.0}$$

$$P(LC) = \frac{5491.0}{8012.58}$$

$$P(LC) = 0.6852973 \cong 0.685$$

This means that 68.5 percent of calls attempted during the busy period will be lost (receive a busy signal). The GOS has been reduced 58.5 percent through the increase in P(LC) from 0.1 to 0.685.

3.3 Network Traffic Equations

a. Generalized traffic equations which permit calculation of probability of a lost call (blocking) for a variety of situations encountered within the DCS are provided herein.

b. The Erlang B equation is used where lost calls are cleared from the system. The Erlang B equation is:

$$P_B(LC) = \frac{\dfrac{\ell_o^{\,n}}{n!}}{1 + \ell_o + \dfrac{\ell_o^{\,2}}{2!} + \ldots + \dfrac{\ell_o^{\,n}}{n!}} \qquad (2)$$

where

$P_B(LC)$ = the probability of a lost call, where lost calls are cleared from system

ℓ_o = the offered load, in erlangs

n = number of circuits

(1) The conditions under which the Erlang B equation is valid are:

(a) The sequence of attempted calls is random, following a Poisson distribution.

(b) The system must be in operation long enough for the initial conditions to be inconsequential.

(2) The Erlang B equation is valid for any service time distribution and provides both the proportion of time that all circuits are busy and the proportion of attempted calls that find all circuits busy.

c. The Erlang C equation is used where lost calls are held in the system (queued) until circuits are available. The Erlang C equation is:

$$P_C(LC) = \frac{\dfrac{\ell_o^{\,n}}{(n-1)!(n-\ell_o)}}{\left[1 + \ell_o + \dfrac{\ell_o^{\,2}}{2!} + \ldots \dfrac{\ell_o^{\,n-1}}{(n-1)!}\right] + \dfrac{\ell_o^{\,n}}{(n-1)!(n-\ell_o)}} \qquad (3)$$

where

$P_C(LC)$ = the probability of a lost call, where lost calls are held in the system until circuits are available

ℓ_o and n are as defined in paragraph 3.3b

(1) The conditions under which the Erlang C equation is valid are:

(a) The sequence of attempted calls is random, following a Poisson distribution.

(b) The system must be in operation long enough for the initial conditions to be inconsequential.

(c) Service times are exponentially distributed.

(d) The offered load (in erlangs) is less than the number of circuits ($\ell_o < n$). This means that the rate of attempted calls cannot exceed the average rate of call completions.

(2) The average waiting time for any order of service, for the conditional case (excluding those calls that don't wait for service) is:

$$t_w = \frac{t_h}{1-(\ell_o/n)} \tag{4}$$

and for the unconditional case (including those calls that don't wait for service) is:

$$t_w = P_C(LC) \frac{t_h}{1-(\ell_o/n)} \tag{5}$$

where

t_w = the average waiting time (s) for service to begin

t_h = the average holding time (s) for all calls

(3) Equations 3, 4, and 5 are valid for any order of service of waiting calls.

d. The Poisson equation is used where calls which are not immediately serviced at the first attempt are held in the system for a period not exceeding the average holding time (t_h) of all calls, and are thereafter cleared from the system. The Poisson equation is:

$$P_p(LC) = \frac{\ell_o^n e^{-\ell_o}}{n!} \tag{6}$$

where

$P_p(LC)$ = the probability of a lost call, where lost calls are held for a period ($t \leq t_h$), and then, if not serviced, are cleared from system

ℓ_o and n are as defined in paragraph 3.3b

The conditions under which the Poisson equation is valid are:

(1) The sequence of attempted calls in random, following a Poisson distribution.

(2) The system must be in operation long enough for the initial conditions to be inconsequential.

PART 4 - EQUIPMENT CHARACTERISTICS

4.1 Introduction. Presented herein are the equipment characteristics for the DCS in the Pacific. Radio and multiplexer equipment characteristics are provided for both the existing and planned LOS, tropo, and satellite systems. In addition, characteristics are provided for those data modems and telegraph multiplexers identified in the DCS-Pacific station profiles. The characteristics for the equipment now in, or planned for, the Pacific were obtained from various sources, including technical manuals, DCS Applications Engineering Manual DCAC-370-185-1 (dated May 1968, no longer published), open literature and periodicals, DCS Europe Vulnerability to Jamming RADC-TR-79 (dated July 1979), and Threat Assessment Report MILSATCOM (dated October 1978).

4.2 Radio Systems

4.2.1 Line-of-Sight (LOS) Radio Systems

4.2.1.1 Analog Radio Systems. Characteristics for the analog LOS radio systems in the DCS-Pacific are presented in figure 4-1. The characteristics include (1) nomenclature or model of the equipment; (2) frequency range, in MHz; (3) output power in watts and dBm; (4) 3-dB emission bandwidth, in MHz; (5) modulation scheme employed at RF and baseband; (6) VF channel capacity; (7) receiver sensitivity, in dBm; (8) receiver noise figure, in dB; (9) IF 3-dB bandwidth, in MHz; (10) required signal level, in dBm; (11) type of combiner used; and (12) types of diversity employed.

4.2.1.2 Digital Radio Systems. Characteristics for the digital LOS radio systems in the DCS-Pacific are presented in figure 4-2. The characteristics include (1) nomenclature or model of the equipment; (2) frequency range, in MHz; (3) output power, in watts and dBm; (4) 3-dB emission bandwidth, in MHz; (5) modulation scheme employed at RF and baseband; (6) mission bit stream (MBS) data rate, in Mb/s; (7) VF channel capacity; (8) receiver sensitivity, in dBm; (9) receiver noise figure, in dB; (10) IF 3-dB bandwidth, in MHz; (11) required signal level in dBm; (12) type of combiner used; and (13) types of diversity employed.

4.2.2 Troposcatter and Diffraction Radio Systems

4.2.2.1 Analog Radio Systems. Characteristics of the analog tropo and diffraction radio systems in the DCS-Pacific are presented in figure 4-3. The characteristics include (1) nomenclature or model of the equipment; (2) frequency range, in MHz; (3) output power, in watts and dBm; (4) 3-dB emission bandwidth, in MHz; (5) modulation scheme employed at RF and baseband; (6) VF channel capacity; (7) receiver sensitivity, in dBm; (8) noise figure, in dB; (9) IF 3-dB bandwidth, in MHz; (10) required signal level, in dBm; (11) type of combiner used; and (12) types of diversity employed.

4.2.2.2 Digital Radio Systems. Characteristics for the digital tropo systems in the DCS-Pacific are presented in figure 4-4. The characteristics include (1) nomenclature or model of the equipment; (2) frequency range, in MHz; (3) output power, in watts and dBm; (4) 3-dB emission bandwidth, in MHz; (5) modulation scheme employed at RF and baseband; (6) MBS data rate, in Mb/s; (7) VF channel capacity; (8) receiver sensitivity, in dBm; (9) noise figure, in dB;

(Text continued on page 4-6)

NOMENCLATURE OR MODEL	FREQUENCY RANGE (MHz)	OUTPUT POWER		3-dB EMISSION BANDWIDTH (MHz)	MODULATION		CHANNEL CAPACITY (VF)	RECEIVER					DIVERSITY EMPLOYED			
		WATTS	dBm		RF	BASEBAND		SENSITIVITY (dBm)	NOISE FIGURE (dB)	IF 3-dB BANDWIDTH (MHz)	REQUIRED SIGNAL LEVEL (dBm)	TYPE OF COMBINER	NON-	FREQ	SPACE	QUAD
AN/FRC-84	7125-8400	1	30	20	FM	SSB-SC	300	-91	14	8	-81	Selection		X		
AN/FRC-109	7125-8400	1	30	20-25	FM	SSB-SC	300	-91	12	9	-81	Equal-Gain	X	X		X
							600	-87	12	20	-77					
							960	-85	12	20	-75					
AN/FRC-149(V)	7125-8400	1	30	10	FM	ISB-SC	600	-88	12	25	-78	Selection*		X		
AN/FRC-154(V)	4400-5000	1	30	25	FM	ISB-SC	240	-85	11	25	-75	Selection		X		
							600	-85	11	25	-75					
AN/FRC-155	4400-5000	1**	30	25	FM	ISB-SC	120	-97	12	12	-87	Selection*		X		
							300	-91.5	12	18	-81.5					
							600	-89	12	25	-79					
AN/FRC-158	7125-8400	1	30	30	FM	ISB-SC	120	-95	12	12	-85	Selection*		X		
							300	-90	12	18	-80					
							600	-84	12	25	-74					
AN/TRC-24	100-225	50-120	45-51	0.75	FM	SSB-SC	12	-114	12	3.5	-104	NA	X			
	225-400	50-120	45-71	0.75	FM	SSB-SC	12	-111	15	3.5	-101	NA	X			
AN/TRC-29	1700-2400	10	40	15	FM	PPM	23/45	-85	16	21	-75	NA	X			
LC-4E	4400-5000	1	30	25	FM	ISB-SC	240	-85	11	25	-75	Selection		X		
							600	-85	11	25	-75					
.I-228 Series	5925-8100	0.7	28.5	20	FM	SSB	240	-91	12	25	-81	Selection*	X	X		
MW-508D	7125-8400	1	30	15	FM	SSB-SC	600	-88	12	25	-78	Selection*		X		X
TR-2GD-300	1700-1800	10	40	5.6	FM	SSB	300	-92	10	5.6	-82	Selection*	X			
TR-7GD-300	7125-7425	1	30	5.6	FM	SSB	300	-92	10	5.6	-82	Selection*		X		X
TR-7GD-600	7125-7425	1	30	1.5	FM	SSB-AM	60	-92	10	1.5	-82	Selection*	X			
				2.4			120	-92	10	2.4	-82					
				5.6			300	-92	10	5.6	-82					
TR-450-03	400-470	1	30	0.74	FM	FM	24	-92	8	1.5	-82	Selection*	X	X		
RML-4	7125-7750	1-2	30-33	30	FM	SSB-SC	60	-98	14	28	-88	Selection*		X		X
	7125-8400	1-2	30-33	25	FM	SSB-SC	60	-98	14	15	-88					

* Estimated. ** Normally used. Application in Pacific area (Philippines) uses 1000 watts (60dBm).
NA - Not applicable

Figure 4-1. Characteristics of analog line-of-sight radio systems.

NOMENCLATURE OR MODEL	FREQUENCY RANGE (MHz)	OUTPUT POWER		3-dB EMISSION BANDWIDTH (MHz)	MODULATION		CHAN CAP (VF)	MBS DATA RATE (Mb/s)	RECEIVER					DIVERSITY EMPLOYED			
		WATTS	dBm		RF	BASEBAND			SENSI-TIVITY (dBm)	NOISE FIGURE (dB)	IF 3-dB BANDWIDTH (MHz)	REQUIRED SIGNAL LEVEL (dBm)	TYPE OF COMBINER	NON-	FREQ	SPACE	QUAD
AN/FRC-162(V)	7125-8400	1	30	14.0	FM	3LPR	192	12.5526	-88	12	25	-78	Selection			X	
AN/FRC-171(V)	7125-8400	0.1-2	20-33	7.0	QPR	PCM	96	6.464	-89	10	14	-79	Selection			X	
				7.0	QPR	PCM	96	6.464	-89	10	14	-79	Selection				
				7.0	QPR	PCM	144	9.696	-81	10	14	-71	Selection				
				7.0	QPR	PCM	192	12.928	-80	10	14	-70	Selection				
				10.5	QPR	PCM	288	19.392	-78	10	21	-68	Selection				
				14.0	QPR	PCM	384	25.856	-77	10	28	-67	Selection				
				7.0	QPSK	PCM	96	6.464	-89	10	14	-79	Selection				
				10.5	QPSK	PCM	144	9.696	-87	10	21	-77	Selection				
				14.0	QPSK	PCM	192	12.928	-86	10	28	-76	Selection				
				20.0	QPSK	PCM	288	19.392	-84	10	40	-74	Selection				
				20.0	QPSK	PCM	384	25.856	-83	10	40	-73	Selection				
AN/FRC-173(V)	7125-8400	0.1-2	20-33	7.0	QPR	PCM	96	6.464	-89	10	14	-79	Selection		X		
				7.0	QPR	PCM	144	9.696	-81	10	14	-71	Selection				
				7.0	QPR	PCM	192	12.928	-80	10	14	-70	Selection				
				10.5	QPR	PCM	288	19.392	-78	10	21	-68	Selection				
				14.0	QPR	PCM	384	25.856	-77	10	28	-67	Selection				
				7.0	QPSK	PCM	96	6.464	-89	10	14	-79	Selection				
				10.5	QPSK	PCM	144	9.696	-87	10	21	-77	Selection				
				14.0	QPSK	PCM	192	12.928	-86	10	28	-76	Selection				
				20.0	QPSK	PCM	288	19.392	-84	10	40	-74	Selection				
				20.0	QPSK	PCM	384	25.856	-83	10	40	-73	Selection				
TPO-2G6MB-1A/ RDPO-2G60-M61A	1700-2400	4		50.0	FM	PCM	96	6.312	-87	10	50	-77	Selection*				X

*Estimated.

Figure 4-2. Characteristics of digital line-of-sight radio systems.

NOMENCLATURE OR MODEL	FREQUENCY RANGE (MHz)	OUTPUT POWER		3-dB EMISSION BANDWIDTH (MHz)	MODULATION		CHANNEL CAPACITY (VF)	RECEIVER					DIVERSITY EMPLOYED			
		WATTS	dBm		RF	BASEBAND		SENSITIVITY (dBm)	NOISE FIGURE (dB)	IF 3-dB BANDWIDTH (MHz)	REQUIRED SIGNAL LEVEL (dBm)	TYPE OF COMBINER	NON-	FREQ	SPACE	QUAD
TO-2G120-2A/ RO-2GA60-1A	1700-2400	20K	73	4.0	FM	ISB-SC	60	-99	8.5	5	-89	Selection*		X		
TO-2G120-2A/ RO-2GA60-1B	1700-2400	1K	60	3.0	FM	ISB-SC	60	-99	8.5	5	-89	Selection*		X		
TO-2G120-2A/ RO-2GA60-2B	1700-2400	2K	63	4.0	FM	ISB-SC	120	-99	8.5	5	-89	Selection*		X		
TO-2G120-2A/ RO-2GA120-2A	1700-2400	2K	63	4.0	FM	ISB-SC	120	-99	8.5	5	-89	Selection*				X
TO-2G120-2A/ RO-2GA120-2B	1700-2400	2K	63	4.0	FM	ISB-SC	120	-99	8.5	5	-89	Selection*		X		
TR-7GD-300	7125-7425	10	40	5.6	FM	SSB	300	-96.5	10	5.6	-86.5	Selection*		X		X

* Estimated

Figure 4-3. Characteristics of analog troposcatter and diffraction radio systems.

NOMENCLATURE OR MODEL	FREQUENCY RANGE (MHz)	OUTPUT POWER		3-dB EMISSION BANDWIDTH (MHz)	MODULATION		CHAN CAP (VF)	MBS DATA RATE (Mb/s)	RECEIVER						DIVERSITY EMPLOYED			
		WATTS	dBm		RF	BASEBAND			SENSI-TIVITY (dBm)	NOISE FIGURE (dB)	IF 3-dB BANDWIDTH (MHz)	REQUIRED SIGNAL LEVEL (dBm)	TYPE OF COMBINER	NON-	FREQ	SPACE	QUAD
OH-20,000	1700-2400	20K	73	7	FM	PCM	96	6.312	-103	2.5	7	-93	Selection*				X

*Estimated

Figure 4-4. Characteristics of digital tropo radio systems.

(10) IF 3-dB bandwidth, in MHz; (11) required signal level, in dBm; (12) type of combiner used; and (13) types of diversity employed.

4.2.3 Satellite Terminal Radio Systems. Characteristics for the satellite terminals in the DCS-Pacific are presented in figure 4-5. The characteristics include (1) nomenclature of the terminal; (2) frequency range, in MHz; (3) output power, in watts and dBm; (4) 3-dB emission bandwidth, in MHz; (5) modulation scheme employed at RF and baseband; (6) receiver sensitivity, in dBm; (7) noise figure, in dB; (8) IF 3-dB bandwidth, in MHz; (9) required signal level, in dBm; (10) antenna diameter, in feet; and (11) antenna gain, in dB, and beamwidth, in degrees, for midband transmit and receive frequencies.

4.3 Multiplexers

4.3.1 Analog Multiplexers. Characteristics for the analog multiplexers in the DCS-Pacific are presented in figure 4-6. The characteristics include (1) nomenclature or model; (2) type of multiplexing employed; (3) modulation used; (4) channel capacity; (5) baseband frequency range, in kHz; and (6) input and output levels, in dBm per channel.

4.3.2 Digital Multiplexers. Characteristics for the digital multiplexers in the DCS-Pacific are presented in figure 4-7. The characteristics include (1) nomenclature or model; (2) type of multiplexing; (3) number of inputs; (4) maximum output data rate in b/s; (5) input and output modulations employed; and (6) data modes capable of being handled (asynchronous or synchronous).

4.4 Data Modems and Telegraph Multiplexers

4.4.1 Data Modems. Characteristics for the data modems in the DCS-Pacific are presented in figure 4-8. The characteristics include (1) nomenclature or model; (2) minimum and maximum data rate, in b/s; (3) modulation scheme used; (4) duplex mode capability (half or full); and (5) data modes capable of being handled (asynchronous or synchronous).

4.4.2 Telegraph Multiplexers. Characteristics of the telegraph multiplexers in the DCS-Pacific are presented in figure 4-9. The characteristics include (1) nomenclature or model; (2) number of teletypewriter channels multiplexed; (3) number of VF channels into which the indicated number of teletypewriter channels are multiplexed; (4) modulation scheme used; (5) multiplex scheme used; (6) maximum speed in bauds; (7) frequency deviation per channel, in Hz; (8) input and output VF signal levels, in dBm per channel; and (9) types of diversity employed.

4.5 Passive Reflectors

4.5.1 Introduction. Passive reflectors are employed on a number of LOS links in the Pacific area to overcome obstructions, reduce the number of active repeaters, or in the case of tower-mounted reflectors, reduce the length of waveguide runs, thus reducing line losses. Two basic types of passive reflectors are employed in the Pacific, (1) the periscope system which is a small passive reflector mounted on the same tower (usually above and within the near-field) as the parabolic antenna and (2) the large billboard reflector which may be installed anywhere between the distant station antennas and may, or may not, be

(Text continued on page 2-13)

NOMENCLATURE OR MODEL	FREQUENCY RANGE (MHz)	OUTPUT POWER		3-dB EMISSION BANDWIDTH (MHz)	MODULATION		RECEIVER				Antenna				
							SENSITIVITY (dBm)	NOISE FIGURE (dB)	IF 3-dB BANDWIDTH (MHz)	REQUIRED SIGNAL LEVEL (dBm)	Dia	Mid-band Gain (dB)		Mid-band Beamwidth (degrees)	
		WATTS	dBm		RF	BASEBAND					(ft)	Transmit	Receive	Transmit	Receive
AN/MSC-46/-66	7250-8400	10K	70	40	FM	SSB-SC* or ISB-SC**	-110	16.5	40	-100	40	57.7	57.0	0.21	0.23
AN/GSC-39	7250-8400	8K	69	40	FM	PSK	-116	10	40	-106	38	57.3	56.6	0.22	0.24
AN/FSC-78	7250-8400	8K	69	40	FM	PSK	-116	10	40	-106	60	61.3	60.6	0.14	0.15
AN/TSC-86	7250-8400	1K	60	8.6	FM	PSK	-116	10	40	-106	20	51.7	51.0	0.42	0.46

* When used with AN/FCC-55(V) multiplexer.
** When used with AN/TCC-78 multiplexer.

Transmit frequency range: 7900-8400 MHz
(Mid-band frequency=8150 MHz)
Receive frequency range: 7250-7750 MHz
(Mid-band frequency=7500 MHz)

Figure 4-5. Characteristics of satellite terminal radio systems.

NOMENCLATURE OR MODEL	TYPE OF MULTIPLEXING	MODULATION	CHANNEL CAPACITY	FREQUENCY RANGE (kHz)	LEVELS: USER SIDE* (dBm/channel) IN	LEVELS: USER SIDE* (dBm/channel) OUT	LEVELS: LINE SIDE (dBm/channel) IN	LEVELS: LINE SIDE (dBm/channel) OUT
AN/FCC-17	FDM	ISB-SC	12 600	60-108 or 60-2540	-16	+7	-25	-40
AN/FCC-18(V) (TCS-600)	FDM	SSB-SC	12 60 120 240 600	60-108 312-552 60-552 60-1052 60-2540	-16	+7	-35 to -25	-45 to -35
AN/FCC-21	FDM	ISB-SC	12 600	60-108 60-2540	-16	+7	-25	-40
AN/FCC-22	FDM	ISB-SC	12 600	60-108 60-2540	-16	+7	-25	-40
AN/FCC-55(V) (Lenkurt Model 46A)	FDM	SSB-SC	12 60 600	60-108 312-552 60-2540	-16	+10	-10 to -50	-10 to -50
AN/MCC-12	FDM	ISB-SC	60 600	12-252 or 60-2540	-16	+7	-25	-40
AN/TCC-7/-50	FDM	SSB-SC	12	12-60 or 60-108	-16	+7	-35	-25
AN/TCC-13	TDM	PPM	23	1-MHz Bandwidth	-4	0	+7	+7
AN/TCC-78	FDM	ISB-SC	72	60-360	-15	-45	-55 to -5	0 to +17
AN/UCC-2(V)	FDM	ISB-SC	24 600	60-156 60-2540	-16	+7	-25	-40
AN/UCC-4(V)	FDM	ISB-SC	12 600	60-108 60-2540	-16	+7	-25	-40

* 4-wire

Figure 4-6. Characteristics of analog multiplexers.

NOMENCLATURE OR MODEL	TYPE OF MULTIPLEXING	MODULATION	CHANNEL CAPACITY	FREQUENCY RANGE (kHz)	LEVELS			
					USER SIDE* (dBm/channel)		LINE SIDE (dBm/channel)	
					IN	OUT	IN	OUT
CT-12C	FDM	SSB-SC	12	6-54 or 60-108	-16	+7	-18	-36
ICCSS**	FDM	ISB-SC	12	60-108	-16	+7	-25	-40
MX-106	FDM	SSB-SC	12 60 600 960	12-60 312-552 60-2540 60-4028	-16	+7	-15	-45
NCM-12A***	FDM	SSB-SC	12	6-54 or 60-108	-16	+7	-25	+6
NCM-48S/120S	FDM	SSB-SC	120	60-552	--	--	--	--
NVT-120S	FDM	SSB-SC	12 60	60-108 312-552	--	--	--	--
RS-1	FDM	SSB-SC	12	12-600	-16	+7	-18	-36
TD-410/UGC	FDM Multiplexer	SSB-SC or ISB-SC	2	0.375-5.915	-25 to +4	NA	NA	-10 to 0
TD-411/UGC	FDM Demultiplexer	SSB-SC or ISB-SC	2	0.375-5.915	-25 to +4	NA	NA	-10 to 0

** 4-wire.
*** Characteristics based on Siemens-Halske VZ-12.
** Assumed same as 12-channel AN/UCC-4 (V).

-- = Not available

Figure 4-6. Characteristics of analog multiplexers (cont).

NOMENCLATURE OR MODEL	TYPE OF MULTIPLEXING	NUMBER OF INPUTS	MAXIMUM OUTPUT DATA RATE (b/s)	MODULATION		DATA MODES	
				INPUT	OUTPUT	ASYNC	SYNC
AN/FCC-95(V)	TDM	12-96 VF	-	Voice	PCM	-	-
AN/FCC-97	2d level TDM	8 ports	12.6 M	PCM	PCM		X
AN/FCC-98 (TD-1192)	1st level MUX	24 VF	1.544 M	Voice or PCM (NRZ)	PCM(NRZ or Bipolar)	X	X
AN/FCC-99 (TD-1193)	2d level TDM	8 ports	12.9 M	PCM(NRZ or Bipolar)	PCM(NRZ or Bipolar)	X	X
AN/GSC-24	TDM	15 data	10 M	-	-	X	X
B310	Cable TDM	24 data	-	-	PCM	-	-
CC-18A	TDM	96 VF	6.312 M	Voice	PCM	-	-
CODEX TDM-920	TDM	64 data	9600	-	-	X	X
HSTDM (CODEX)	High Speed TDM	8 data	9600	-	-		X
LSTDM (CODEX)	Low Speed TDM	15 data	1200	-	-	X	X
- Not Available							

Figure 4-7. Characteristics of digital multiplexers.

NOMENCLATURE OR MODEL	DATA RATE (b/s) MINIMUM	DATA RATE (b/s) MAXIMUM	MODULATION	DUPLEX MODE(S) HALF	DUPLEX MODE(S) FULL	DATA MODES ASYNC	DATA MODES SYNC
AN/USC-26	19.2K	153.6K	7LPR or 3LPR	X	X		X
CODEX 1200		1200	QAM	-	-	-	-
CODEX 4800(MSCIT)	3200	4800	QAM		X		X
CODEX 9600 (HSCIT)	4800	9600	QAM		X		X
CODEX LSI-9600	4800	9600	QAM		X		X
DS-9601 (Rixon)	-	9600	AM/VSB	X	X		X
MD-674(P)/G	150*	1200	FSK	-	-	X	X
MD-701/UY	600	2400	FSK	-	-	-	-
MD-920/G	19.2K	10M	Bipolar-to-NRZ		X	-	-
MD-921/G	19.2K	10M	BPSK-to-NRZ		X	-	-
MD-1002	16K	10M	BPSK	-	x	-	x
MD-1002	50K	10M or 20M	QPSK	-	x	-	x
207C	150	2400	DCPSK	-	-		X

*Maximum for asynchronous data.

- Not available

Async = Asynchronous
Sync = Synchronous

Figure 4-8. Characteristics of data modems.

NOMENCLATURE OR MODEL	NUMBER OF TTY CHANNELS MULTIPLEXED	NUMBER OF VF CHANNELS REQUIRED	MODULATION	MULTIPLEX SCHEME	MAXIMUM SPEED (bauds)	FREQUENCY DEVIATION PER CHANNEL (Hz)	VF SIGNAL LEVEL (dBm/channel)		TYPE OF DIVERSITY
							INPUT	OUTPUT	
AN/FCC-19	16	1	FSK	FDM	90	±42.5	-45 to +5	-40 to -5	--
AN/FCC-25	32	2	FSL	FDM	90	±42.5	-45 to +5	-40 to -5	--
AN/FCC-37	16	1	FSK	FDM	90	±42.5	-46 to +5	-10	--
AN/FCC-38	16	1	FSK	FDM	90	±42.5	-76 to +5	-23	--
AN/FCC-39	8+	1	FSK	FDM	90	±42.5	-76 to +5	-23	--
	4	1	FSK	FDM	200	±85.0	-76 to +5	-23	--
AN/FCC-66	16	1	FSK	FDM	75	--	--	--	Spare
AN/FCC-67	16	1	FSK	FDM	75	--	--	--	None
AN/FCC-68	8+	1	FSK	FDM	75	--	--	--	None
	4	1	FSK	FDM	188	--	--	--	None
AN/FCC-69	16	1	FSK	FDM	75	--	--	--	None
AN/FCC-70	16	1	FSK	FDM	75	--	--	--	None
AN/FCC-72	8	1	FSK	FDM	75	--	--	--	None
AN/FGC-60(V)	16	1	FSK	FDM	80	±42.5	-10	-10	Dual/Quad.
25A	25	1	FSK	FDM	75	±30.0	-50 to +0	-27 to +5	--
2000-8	8	1	FSK	FDM	80	±42.5	-40 to +5	to +3	Quad.
2002-22	22	1	FSK	FDM	75	±30.0	-45 to +5	-20 to +3	None
2002-22H	22	1	FSK	FDM	30	±30.0	-45 to +5	-20 to +3	None
2344A	--	--	--	--	--	--	--	--	--
2394B	18	1	FSK	FDM	110	--	--	--	--
2400-M-1-C	--	--	--	--	--	--	--	--	--
4800-Data	--	--	--	--	--	--	--	--	--
DATAX-N200	--	--	--	--	--	--	--	--	--
-- = Not available									

Figure 4-9. Characteristics of telegraph multiplexers.

within the near-field of one or the other. In some instances, because of peculiar path geometry, double billboard reflectors are employed. The method of calculating gain for passive reflectors is the same for either the periscope system or the billboard system. The two basic passive reflector configurations are shown in figure 4-10.

4.5.2 Passive Reflector Gain. The gain of a passive reflector is determined by the following procedure:

a. Determination of the effective area of the reflector:

$$a^2 = A \cos \alpha \tag{1}$$

where

a^2 = the effective area of the reflector (ft^2)

A = the actual area of the reflector (ft^2)

α = the angle of incidence--the angle between the boresight of the parobolic antenna and the normal to the surface of the passive reflector (degrees)

b. Determination of the wavelength:

$$\lambda = 0.9836/f_{GHz} \quad \text{(ft)} \tag{2}$$

c. Determination as to whether the passive reflector is in the near-field of the parabolic antenna:

$$k_o = \frac{\pi \lambda d}{4a^2} \tag{3}$$

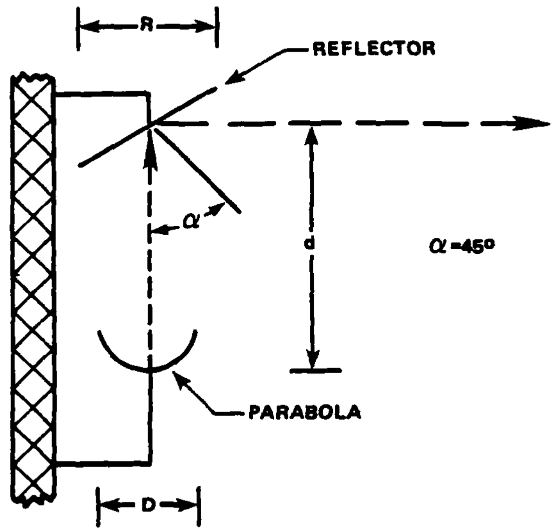
where

k_o = parameter used to determine whether passive reflector is in the near-field of parabolic antenna

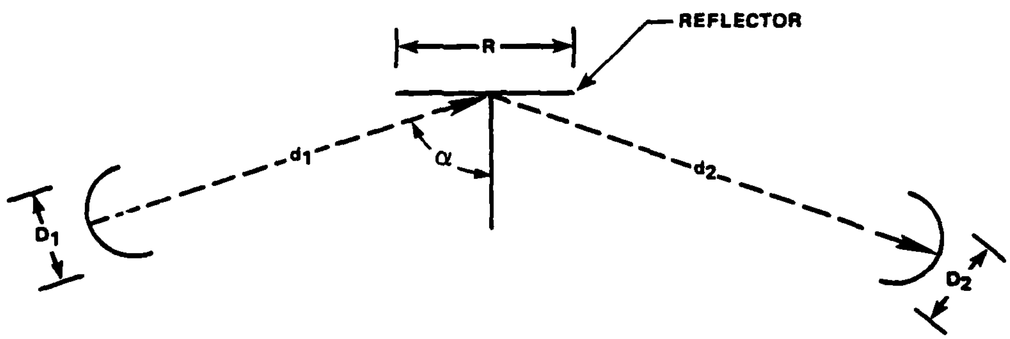
d = distance between antenna and passive reflector (ft)

If $k_o > 2.5$, the passive reflector is not in the near-field, and the gain is calculated as follows:

$$G_{PR} = 20 \log \left(\frac{4\pi a^2}{\lambda^2} \right) \quad \text{(dB)} \tag{4}$$



(a) PERISCOPE SYSTEM (SIDE VIEW)



(b) BILLBOARD SYSTEM (OVERHEAD VIEW)

WHERE:
R = LARGEST DIMENSION OF PASSIVE REFLECTOR (FEET)
d = DISTANCE BETWEEN ANTENNA AND PASSIVE REFLECTOR (STATUTE MILES)
D = DIAMETER OF PARABOLIC ANTENNA (FEET)
α = ANGLE OF INCIDENCE (DEGREES)

Figure 4-10. Passive reflectors.

where

G_{PR} = gain of the passive reflector (dB)

If $k_o \leq 2.5$, the passive reflector is in the near-field, and the gain is determined by first calculating the parameter, r_o:

$$r_o = D \sqrt{\pi / 4a^2} \quad (5)$$

where

r_o = parameter used in calculating near-field gain of passive reflector

D = diameter of parabolic antenna (ft)

The near-field gain is then determined from figure 4-11, using parameters k_o and r_o.

4.5.3 Sample Calculation

a. To illustrate the method of determining passive reflector gain, a sample calculation is provided. The example is LOS link M1085 between Kadena and Naha, in Okinawa. The Kadena terminal employs a periscope system, with an 8 by 12 foot rectangular reflector mounted 47 feet above a 6 foot parabolic antenna. Although the link employs frequency diversity, only one frequency is used in the following calculations in the interest of brevity.

b. The effective area of the reflector from equation 1 is:

$$a^2 = A \cos \alpha$$

where

$A = 8 \times 12 \text{ ft} = 96 \text{ ft}^2$

$\alpha = 45^o$

and

$$a^2 = 96 \cos (45) = 67.9 \text{ ft}^2$$

c. The wavelength at the frequency of interest, 4.712 GHz is:

$$\lambda = 0.9836/f_{GHz}$$

$$\lambda = 0.9836/4.712$$

$$\lambda = 0.209 \text{ ft}$$

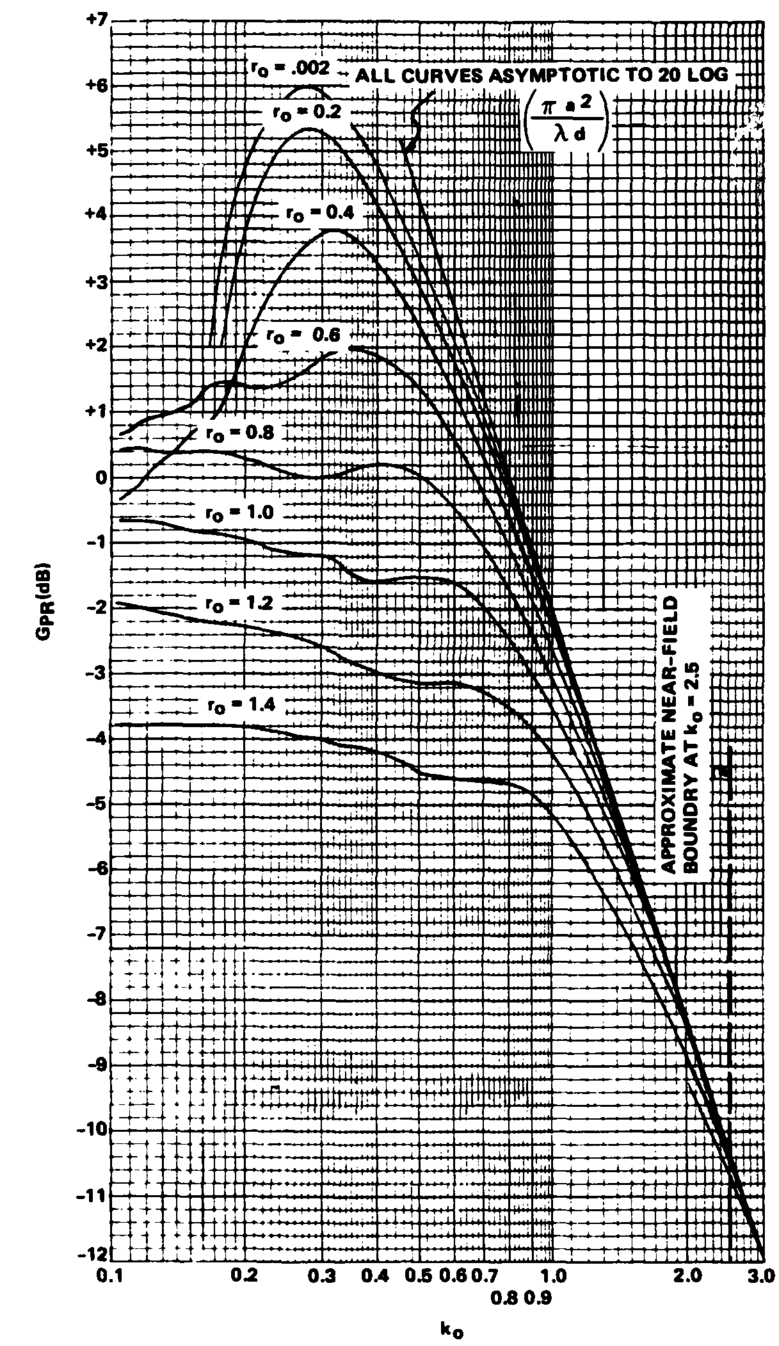


Figure 4-11. Near-field gain for rectangular passive reflectors.

d. To determine whether the reflector is in the near-field of the parabolic antenna, calculate k_o:

$$k_o = \frac{\pi\lambda d}{4a^2} = \frac{\pi(0.209)(47)}{4(67.9)} = \frac{30.9}{271.6} = 0.11$$

Since $k_o < 2.5$, the passive reflector is in the near-field.

e. To determine the near-field gain, first calculate r_o:

$$r_o = D\sqrt{\pi/4a^2}$$

$$r_o = 6\sqrt{\pi/271.6}$$

$$r_o = 0.65$$

f. The near-field gain is determined from figure 4-11 for $k_o = 0.11$ and $r_o = 0.65$ --

(1) Finding $k_o = 0.11$ along the abscissa of the graph.

(2) Finding the curve for $r_o = 0.65$--actually by interpolating between the curves for $r_o = 0.6$ and $r_o = 0.8$.

(3) Determining the gain, G_{PR} (dB), on the ordinate--$G_{PR} = +\ 0.6$ dB (by interpolation) which was rounded off to 1 dB for this study.

4.5.4 Propagation Loss. Calculation of propagation path loss for links using passive reflectors depends upon the type of configuration used. In the case of the periscope system, only the propagation path loss between the distant terminals is used, since the reflector is in the near-field of the parabolic antenna. In the case where a billboard passive reflector is in the near-field of one parabolic antenna, only the propagation loss between the billboard and the distant antenna (far-field distance) is used. In the case where the billboard reflector is in the far-field of both antennas, the propagation path loss between the billboard and each antenna must be calculated. Propagation loss (L_s) for the far-field condition is calculated by:

$$L_s = 97 + 20 \log f + 20 \log D \quad \text{(dB)} \tag{6}$$

where

f = frequency (GHz)

D = path length (statute miles)--use d_1 and/or d_2 from figure 4-10(b)

PART 5 - REFERENCES

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